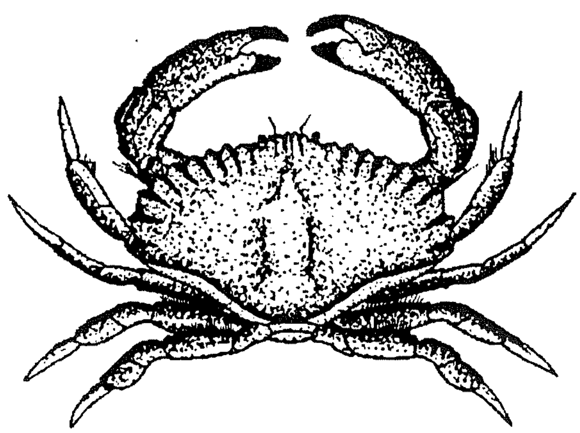
WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

Sediment Cleanup Standards User Manual

-- First Edition --

Washington Department of Ecology
Sediment Management Unit



December, 1991

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LIST OF ACRONYMS

ARAR	applicable or relevant and appropriate requirement
AVS	acid volatile sulfide
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
Corps	U.S. Army Corps of Engineers
DNR	Washington Department of Natural Resources
Ecology	Washington Department of Ecology
EPA	U.S. Environmental Protection Agency
GIS	Geographic Information System
MCUL	minimum cleanup level
MTCA	Model Toxics Control Act
NPDES	National Pollutant Discharge Elimination System
PSEP	Puget Sound Estuary Program
QA/QC	quality assurance and quality control
SEPA	State Environmental Policy Act
SQS	Sediment Quality Standards
SRZ	sediment recovery zone
TOC	total organic carbon
WARM	Washington Ranking Method
WPCA	Water Pollution Control Act

1. INTRODUCTION

1.1 Purpose

The purpose of this document is to provide guidance to Ecology staff on implementing Part V, *Sediment Cleanup Standards*, of the Sediment Management Standards, Chapter 173-204 WAC, adopted by the Washington Department of Ecology (Ecology) on 27 March 1991. This document is intended for use by Ecology staff in implementing the sediment cleanup decision process for contaminated sediments in Washington State.

The goal of the Sediment Management Standards is to reduce and ultimately eliminate adverse effects on biological resources and significant threats to human health from surface sediment contamination. The sediment cleanup decision process governs the cleanup of contaminated sediment sites, including how sites are identified, studied, cleaned up, and monitored. The numerical standards in the rule apply only to marine sediments in Puget Sound. Standards for freshwater sediments, low-salinity sediments, and marine sediments outside of Puget Sound are currently reserved and will be addressed on a case-by-case basis by Ecology's Sediment Management Unit.

1.2 Rule Background

Sediments in several areas of Puget Sound and throughout Washington State are contaminated with toxic substances, such as petroleum-derived compounds, chlorinated organic compounds, and metals. Areas with sediment contamination have been associated with impacts to local fish and shellfish. In several of these areas, local health departments have advised residents to limit their consumption of seafood.

Several state laws provide Ecology with the authority to address sediment contamination issues in Washington State waters. Of particular importance, the Water Pollution Control Act (WPCA), Chapter 90.48 RCW, provides Ecology with the authority to regulate and manage discharges to control impacts on sediment quality. In addition, the Model Toxics Control Act (MTCA), Chapter 70.105D RCW, enables Ecology to regulate environmental cleanups. The Sediment Management Standards provide Ecology with a uniform set of procedures and requirements to manage contaminated sediments. The goals of the Sediment Management Standards may be achieved by coordinating activities to comply with other state and federal statutes, such as the MTCA; WPCA; Comprehensive Environmental Response, Compensation and Liability Act (CERCLA); and State Environmental Policy Act (SEPA).

The Sediment Management Standards address three main issues. First, the rule establishes both narrative and numerical Sediment Quality Standards (SQS). These standards correspond to the long-term goals for sediment quality in Washington State waters. Sediments that meet the SQS criteria are expected to have no adverse effects on biological resources and pose no significant risks to human health. The numerical SQS are based on chemical criteria and the results of biological testing. The numerical SQS may be revised as new data are developed regarding the toxicity of contaminants in Puget Sound to human health and the environment. Ecology is currently in the process of developing SQS that are protective of human health.

Second, the Sediment Management Standards set forth a process for managing sources of sediment contamination. This portion of the rule includes 1) mechanisms for verifying that discharges with the potential to impact receiving sediments have received all known, available, and reasonable methods of prevention, control, and treatment prior to discharge and the application of best management practices; 2) monitoring procedures necessary for evaluating the potential for a discharge to impact the receiving sediments; 3) procedures for determining whether a source is eligible for a sediment impact zone, which would authorize the receiving sediments to exceed the SQS; and 4) methods for determining what restrictions (e.g., on size or level of contamination) would apply if such a sediment impact zone is authorized.

Third, the Sediment Management Standards set forth a decision process for identifying contaminated sediment areas and determining appropriate cleanup responses. This process, known as the sediment cleanup decision process, includes screening and ranking of contaminated areas to focus limited resources on areas of sufficient concern to warrant active cleanup. In addition, the process includes procedures for selecting an appropriate cleanup alternative and cleanup standards on a site-specific basis. One goal of the sediment cleanup decision process is to provide a framework for expeditious cleanup decisions and timely cleanup of contaminated sediment sites.

Three guidance documents are available to aid agency personnel or other parties in the implementation of the Sediment Management Standards. This document focuses specifically on providing guidance on the implementation of the sediment cleanup decision process. A second document provides guidance on the use of SEDRANK, a scoring procedure that will be used as a tool to rank contaminated sediment areas. The third document provides guidance on the implementation of sections of the rule that address source control.

1.3 Report Overview

The chapters of this guidance document follow the organization of the sediment cleanup decision process presented in Chapter 173-204 WAC Part V, *Sediment Cleanup Standards*. Chapter 1 provides an introduction to this guidance document and to the rule. Chapters 2 through 11 provide guidance on the sediment cleanup decision process, which is illustrated in Figure 1-1. In this figure, the central column represents technical activities and the two outer columns identify agency decision points. The activities presented in Figure 1-1 are explained in the following chapters:

- Chapter 2 describes station cluster identification and screening (WAC 173-204-510 to WAC 173-204-520)
- Chapter 3 describes the procedures and requirements for hazard assessment (WAC 173-204-530)
- Chapter 4 describes site identification (WAC 173-204-530)
- Chapter 5 describes site ranking and site listing (site ranking is described more fully in a companion guidance document) (WAC 173-204-540)
- Chapter 6 describes types of cleanup and how to determine the regulatory authority that applies at a site (WAC 173-204-550)
- Chapter 7 describes the contents of the cleanup study and the cleanup study reports, including data requirements (WAC 173-204-560)
- Chapter 8 describes delineation of site units and the selection of cleanup standards for each (WAC 173-204-570)
- Chapter 9 describes cleanup actions that are available and how to select cleanup actions for a site (WAC 173-204-580)
- Chapter 10 describes the use of sediment recovery zones (WAC 173-204-590)
- Chapter 11 describes monitoring requirements (WAC 173-204-600).

Following the references, a glossary of terms and a subject index correlating cleanup activities to sections of the rule and the guidance document are provided. Blank worksheets for station cluster screening and site identification are provided in Appendix A, and associated reference tables are provided in Appendix B. Methods for predicting

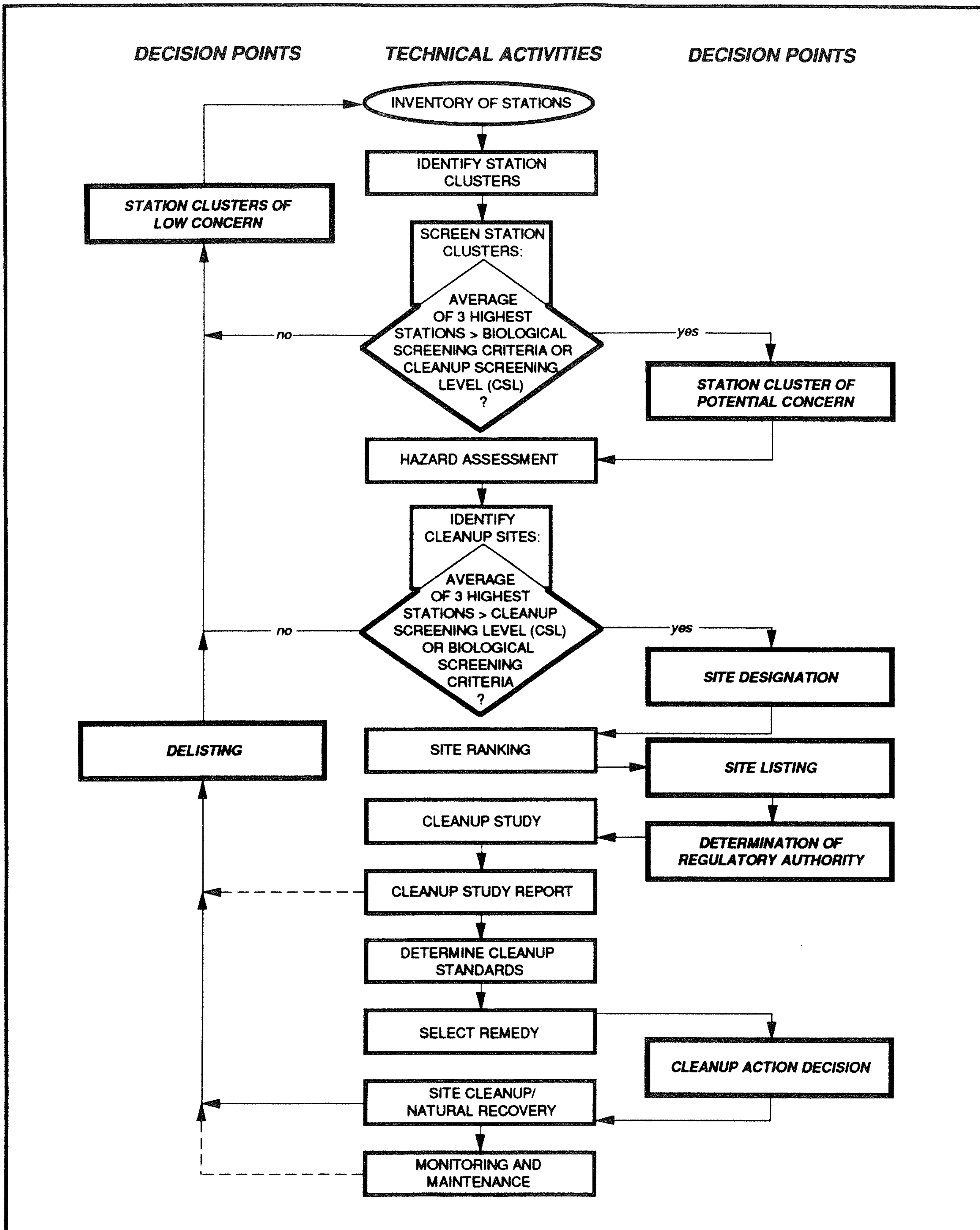

Figure 1-1. Contaminated sediments cleanup decision process.

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natural recovery are described in Appendix C. A discussion of cleanup alternatives for sediments is provided in Appendix D. Finally, the total value approach to weighing costs and net environmental benefits is described in detail in Appendices E and F.

1.4 Implementation Strategy

—RESERVED—

[NOTE—It may be appropriate here to have one or two paragraphs describing which portions of the document are meant to be used by whom. For example, one could say that only the Sediment Management Unit will perform station cluster identification and screening, site identification, and site ranking. Oversight of the hazard assessment and all steps following site ranking could be performed by Ecology or the U.S. Environmental Protection Agency (EPA) (to be discussed in more detail under Chapter 6, *Type of Cleanup and Determination of Regulatory Authority*). Finally, portions of the document that could be provided as guidance to parties conducting voluntary cleanups could be identified; for example, guidance for conducting hazard assessments, cleanup studies and report requirements, and monitoring. A checklist for agency staff is included, identifying the administrative steps that a site manager would follow throughout the sediment cleanup decision process (Table 1-1).]

TABLE 1-1. SITE MANAGER'S IMPLEMENTATION CHECKLIST

Activity	Citation	Trigger	Requirements
Station cluster screening (Round 1)		Identification of a station cluster of potential concern	1. Notify database manager at Sediment Management Unit and file supporting paperwork
	WAC 173-204-510(3)		2. Notify all affected landowners, lessees, onsite dischargers, adjacent dischargers, and other potentially affected parties before conducting hazard assessment
Hazard assessment	WAC 173-204-530(2)	Beginning of hazard assessment	1. Request listed information from landowners, lessees, onsite dischargers, and adjacent dischargers
			2. Request relevant information from Washington Department of Ecology (Ecology), U.S. Environmental Protection Agency (EPA), Washington Department of Natural Resources (DNR), and county and city agencies
Stati[illegible] cluster screening ([illegible] Sit[illegible]ation		Identification of a station cluster as a site	1. Notify database manager at Sediment Management Unit and file supporting paperwork
	WAC 173-204-540		2. Request Sediment Management Unit to rank the site and place the site on the contaminated sediment site list
Cleanup study planning	WAC 173-204-550	Selection of a site for cleanup	1. Determine regulatory authority and type of cleanup
			2. Begin coordination with other affected agencies (e.g., EPA, DNR, U.S. Army Corps of Engineers)
	WAC 173-340-330 WAC 173-340-600		3. If Model Toxics Control Act (MTCA) is chosen as the regulatory authority, request Toxics Cleanup Program to place site on the hazardous waste sites list; follow public notice requirements of MTCA
	Chapter 197-11 WAC		4. Determine whether Environmental Impact Statement (EIS) or other State Environmental Policy Act (SEPA) compliance document is needed
			5. Issue consent decree or agreed order, if appropriate

TABLE 1-1. (Continued)

Activity	Citation	Trigger	Requirements
Cleanup study	WAC 173-204-560(1) WAC 173-204-580(5)	Submittal of cleanup study plans	1. Review cleanup study plan, public information and education plan, sampling and testing plan, and health and safety plan; provide opportunity for public comment and landowner review of plans 2. Issue written approval of plans, approval of plans with revisions, or disapproval of plans to proponents of cleanup study
Cleanup action decision	WAC 173-204-580	Submittal of cleanup study report	1. Review cleanup study report; provide opportunity for public comment and landowner review of the cleanup study report 2. Issue a written cleanup action decision to the proponent of the cleanup action approving one alternative, approving a revised alternative, or disapproving all alternatives
Sediment recovery zone authorization	WAC 173-204-590	Approval of cleanup action alternative leaving wastes in place above Sediment Quality Standards (SQS)	1. Notify all landowners affected by the proposed sediment recovery zone; allow for a landowner comment period to review the sediment recovery zone application 2. Issue written sediment recovery zone authorization as part of cleanup action decision
Delisting	WAC 173-204-540(6)	Completion of all cleanup actions and/or closure of sediment recovery zones	1. Review all documentation to ensure cleanup standards have been achieved 2. Provide public notice and comment period 3. Request Sediment Management Unit to remove the site from the contaminated sediment site list

2. STATION CLUSTER IDENTIFICATION AND SCREENING

WAC 173-204-510 through 173-204-520

2.1 Purpose

One of the first steps in the decision process is to identify clusters of stations that have similar types of contamination and may be associated with the same source or sources. Once station clusters are identified, the clusters are screened to identify areas where contaminated sediments may pose a threat to human health or the environment. This preliminary screening step is intended to focus regulatory resources on those areas that may be of concern.

Currently, station cluster identification and screening is based only on environmental effects. As methods for predicting risks to human health from contaminants in sediments improve, procedures for station cluster identification and screening based on risks to human health may become available. Areas screened out at this stage receive no additional attention unless new information becomes available that indicates the potential for hazards to be associated with the area. Station clusters of potential concern that are identified through this process are further evaluated during the hazard assessment (described in Chapter 3).

2.2 Station Cluster Identification

A station cluster is a set of stations for which chemical and/or biological data exist that, when taken as a whole, identify an area of sediments that is contaminated. To be useful for the ultimate purposes of site identification and cleanup, the sediments within the station cluster should have a similar type of chemical contamination and should be associated with the same source or sources of contamination. Stations in Puget Sound for which chemical and biological data have been collected are entered into a central database, or inventory of stations, maintained by the database manager of the Sediment Management Unit at Ecology, in accordance with the requirements of WAC 173-204-350. This database is used to identify sediments in Puget Sound that may need to be cleaned up by 1) identifying stations at which the sediments fail the SQS or cleanup screening levels (CSLs), and 2) grouping individual stations into clusters of stations that have similar types of contamination. The first step is performed automatically in the database. The procedure for the second step, described below, requires a combination of geographic and mathematical data and incorporates best professional judgment.

2.2.1 Identifying Contiguous Stations

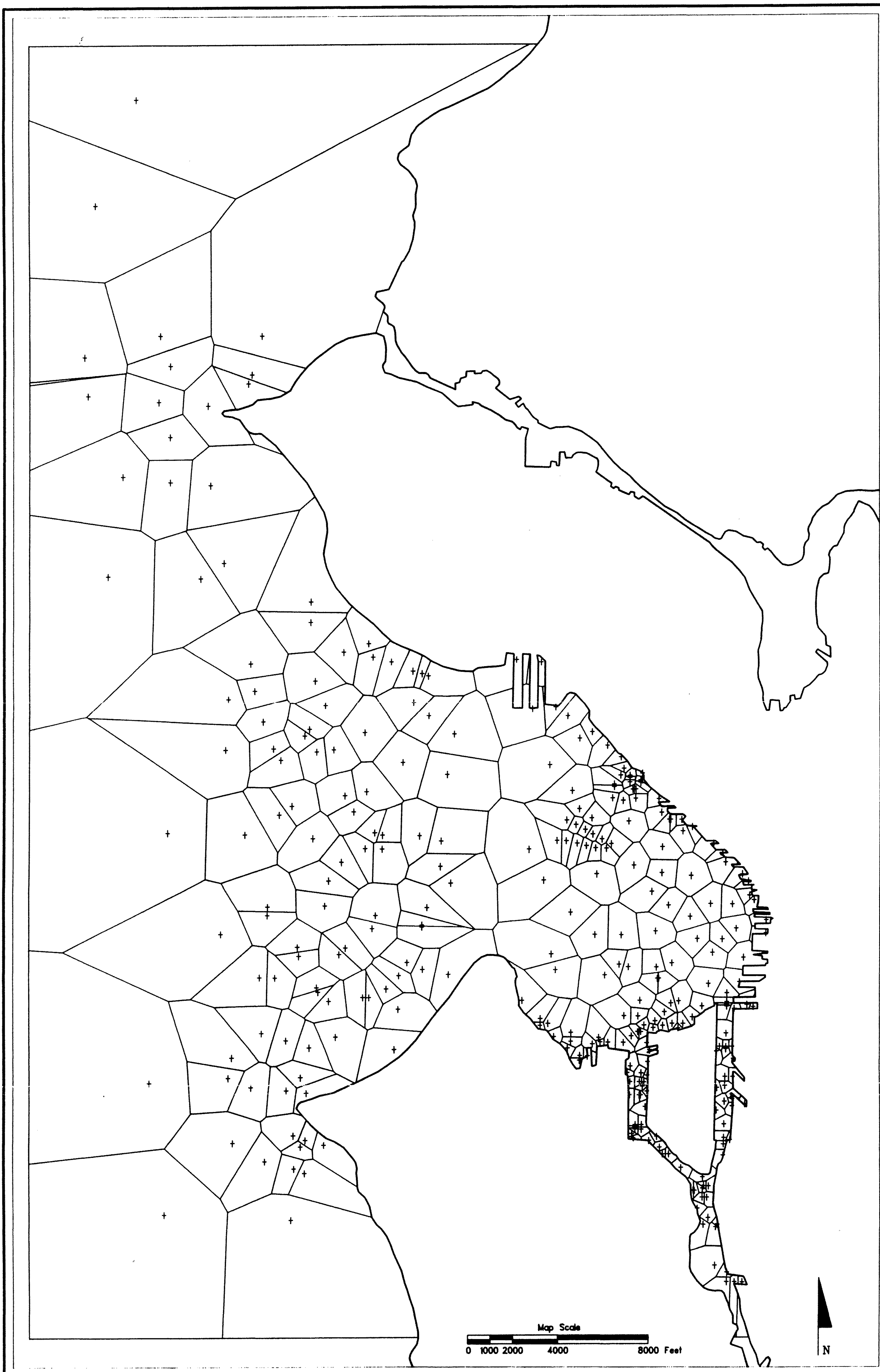
As defined in WAC 173-204-510, a station cluster consists of at least three stations that are contiguous. Thiessen polygons are used to determine whether stations are contiguous; a Thiessen polygon is a polygon around a station within which all points are closer to that station than to any other station. Figure 2-1 shows an example of Thiessen polygons for stations in Elliott Bay. Stations are considered contiguous if they share one side of a polygon. Stations that share only corners are not considered contiguous.

Thiessen polygons may be generated automatically by a Geographic Information System (GIS) or by hand using the following prodedure:

1. Draw straight lines (radii) from each station to every other station that can be reached without crossing any other lines.

2. Construct the perpendicular bisectors of the radii drawn in Step 1. These bisectors will form the edges of the polygons.

3. Extend these edges until they connect with another edge. Remove any portion of a perpendicular bisector that extends beyond the point where it connects with another edge. Remove the original radii.



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Scale 1 inch = 4000 feet

Plot Date: June 24, 1991

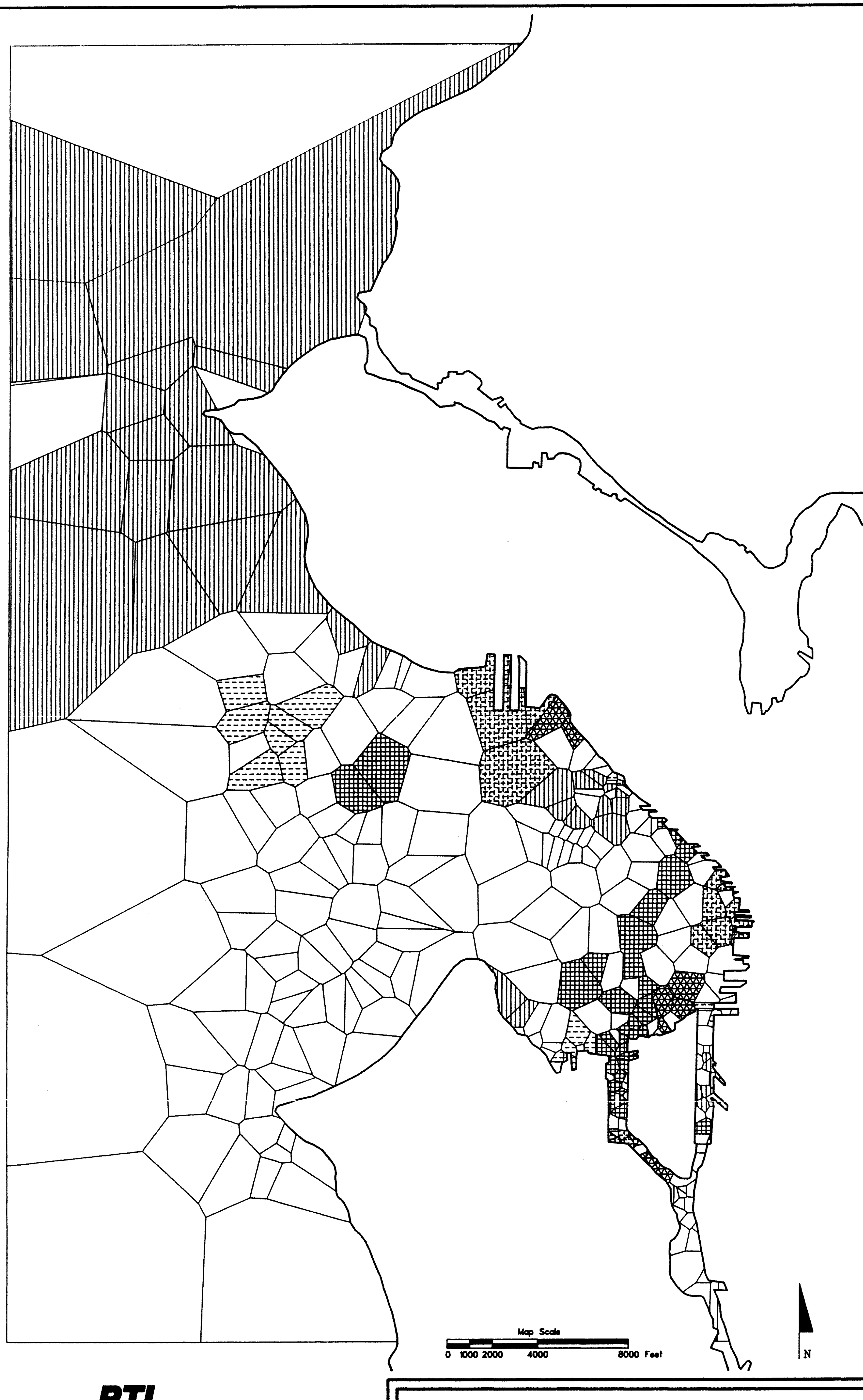
Figure 2-1. Example of Thiessen polygons for stations around Elliott Bay.

Stations at the border of an area will not be completely enclosed by polygons. To complete the polygons around border stations, a set of imaginary stations may be constructed outside the border. It is recommended that the distance from the border station to the imaginary stations be equal to the distance from the nearest interior station to the border station. Closure of border polygons is not necessary to identify contiguous stations, but may be important to determine other attributes of the stations, such as the area associated with border stations.

2.2.2 Grouping Contiguous Stations into Station Clusters

Contiguous stations are grouped into station clusters based on the similarity of their chemical contamination. Because the long-term success of sediment cleanup depends in part on source control, the source of sediment contamination is a reasonable basis for determining similarity. Ideally, sediments contaminated by the same sources should not be clustered with sediments contaminated by different sources. Stations that are affected by the same source(s) of contaminants are expected to be characterized by similar suites of contaminants exceeding the SQS. The relative degree of contamination by different chemicals should also be similar from station to station. However, the amount by which a chemical exceeds the SQS is likely to decrease with distance from the source, or otherwise vary within the area affected by the source. Various mathematical approaches for determining similarity based on these factors are described in detail in PTI (1991c); the recommended approach is outlined below.

A measure of the similarity in chemical contamination between two stations is termed the *similarity index*. The similarity index between two stations is a number between 0 and 1; 0 means that the two stations are completely different, and 1 means that the two stations are exactly the same in terms of the types and levels of chemical contamination associated with each. First, the chemicals that exceed the SQS at each station should be identified and the exceedance factors calculated (an exceedance factor is the ratio of the chemical concentration to the SQS for that chemical). The recommended method for calculating a similarity index takes into consideration the number of chemicals that exceed SQS at both stations and the relative ordering of the exceedance factors for these chemicals. To be similar, the two stations would have 1) many of the same chemicals exceeding the SQS, and 2) a pattern of contamination that is similar (e.g., the same chemicals would have the highest exceedance factors or the lowest exceedance factors at both stations). Computer code (compatible with the database inventory of stations) for



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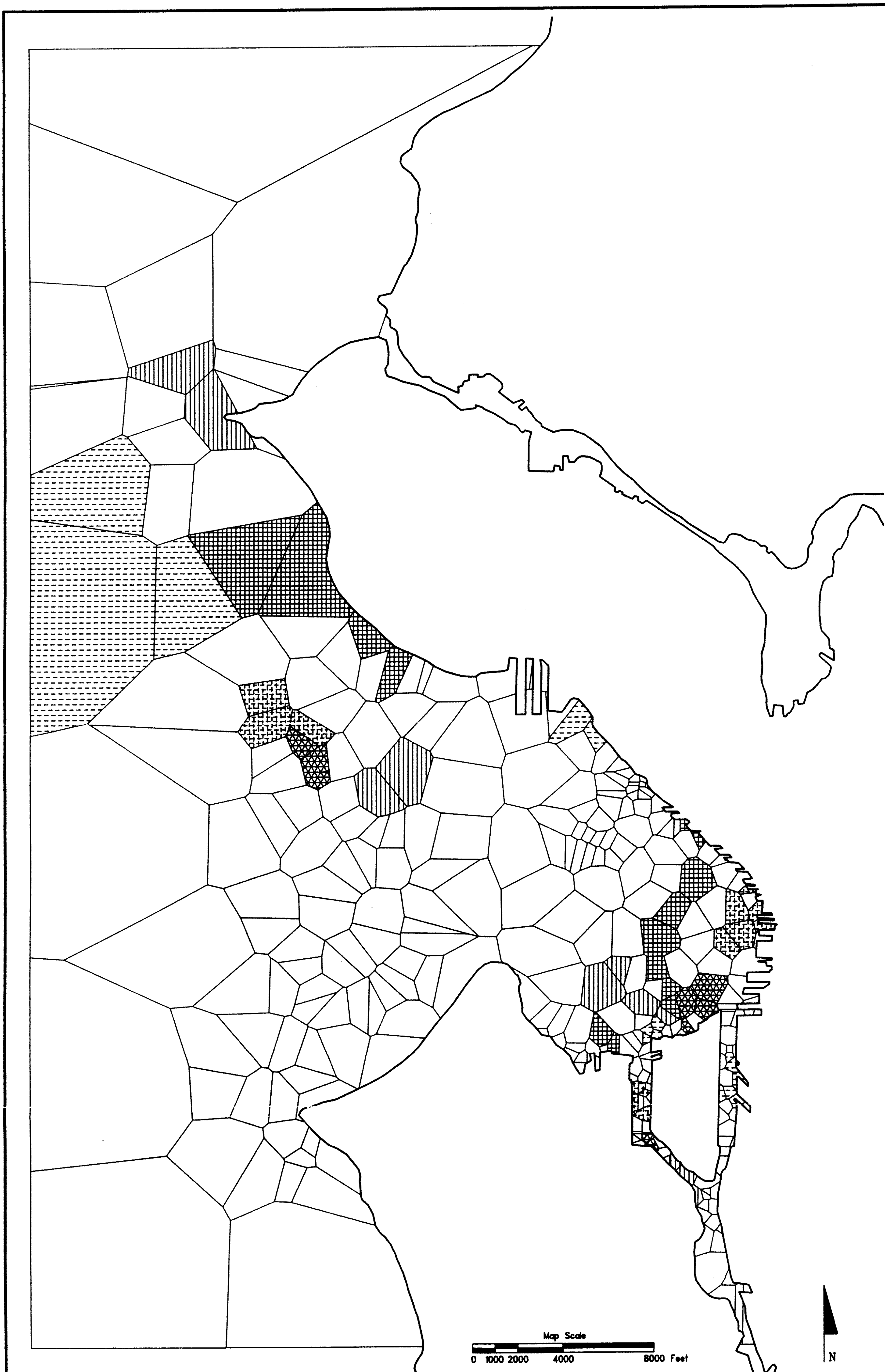
Scale 1 inch = 4000 feet Plot Date: June 05, 1991

Figure 2-2. Clusters defined by similarity index ≥0.4.



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Scale 1 inch = 4000 feet

Plot Date: June 05, 1991

Figure 2-3. Clusters defined by similarity index ≥0.8.

calculating similarity indices is listed in PTI (1991c) and is available from the Sediment Management Unit at Ecology.

For the similarity index to be accurate, it is important that the two stations being compared have similar types of chemical data. For example, if one station has only data on metals concentrations and the other station has mostly data on concentrations of organic chemicals, a mathematical estimate of their similarity will not be meaningful. In addition, the similarity index becomes more sensitive as data for more contaminants are included in the analysis. If data for only a few contaminants are available for a station or stations, use of a similarity index may not be appropriate. When data for individual stations are incomplete, best professional judgment should be used to determine whether these stations should be included in station clusters identified using more complete data sets for nearby areas.

Once similarity indices for pairs of stations in an area have been calculated, contiguous stations with sufficiently high similarity indices are combined into station clusters. A cutoff point for the similarity index must be chosen above which two stations are considered to be similar. For example, one could stipulate that a pair of stations with a similarity index above 0.4 are similar enough to be part of the same station cluster. Various cutoff points may be used; cutoff points between 0.4 and 0.8 generally produce the best results. A lower cutoff point will combine more stations together, resulting in a small number of larger station clusters (Figure 2-2; historical data for Elliott Bay), while a higher cutoff point will tend to result in a large number of smaller station clusters or fragments of station clusters (Figure 2-3; historical data for Elliott Bay). It is recommended that groups of stations defined by two or three different cutoff points be mapped and that best professional judgment be used to assemble the final station clusters, including consideration of known sources to the area.

2.3 Data Requirements

Data requirements to support regulatory decisions generally increase throughout the sediment cleanup decision process, beginning with the least stringent requirements for station cluster identification. These requirements become increasingly stringent for station cluster screening and site designation; the most stringent data requirements are for developing and selecting a cleanup action alternative.

2.3.1 Sediment Chemistry

Information on sediment chemistry is required for at least three contiguous (adjacent) stations to form a station cluster. The chemistry data must meet data quality requirements for Level 3 or better (see Table 2-1 for a description of data quality levels).

Sediment chemistry data that are less than 10 years old are preferable for use in site screening. Older data may not be representative of current conditions at the site because of various processes that may affect natural recovery at the site. This is particularly true if the source of contamination is known or suspected to be primarily historical and the contaminant(s) of concern degrade rapidly in the environment, or if the station cluster is in an area with a high sedimentation rate. Older data in the database may be used at the discretion of Ecology. However, if such data are used to screen station clusters, additional effort during the hazard assessment should be placed on obtaining existing data that are more representative of current conditions at the site.

The primary source of sediment chemistry data for identifying station clusters is the inventory, or database, of Puget Sound data maintained by the database manager at the Ecology Sediment Management Unit (WAC 173-204-350). In some cases, data may not be available in the database for sediments near a known or suspected source. In these situations, sufficient data to begin the station cluster identification and screening process may be collected by Ecology request, a Class II facility inspection, or as part of permitting activities through other agencies, including the Washington Department of Natural Resources (DNR) and the U.S. Army Corps of Engineers (Corps).

2.3.2 Biological Tests

Data on biological effects may be used independently to identify station clusters of potential concern. Data requirements for biological tests are

TABLE 2-1. LEVELS OF DATA QUALITY FOR HISTORICAL DATA

Level 1	**Data are acceptable for all project uses.** The data are supported by appropriate documentation that confirms their compliance with quality assurance and quality control requirements listed in Puget Sound Estuary Program protocols or other methods authorized by Ecology and allows comparison with data that will be generated during the cleanup study.
Level 2	**Data are acceptable for most project uses.** Appropriate documentation may not be available to confirm conclusions on data quality or to support legal defensibility. These data are supported by a summary of quality control information, and the environmental distribution of contamination suggested by these data is comparable to the distribution suggested by other studies. The data are thus considered reliable and potentially comparable to data that will be produced during the cleanup study.
Level 3	**Data are acceptable for screening-level analyses.** The data can be used to estimate the nature and extent of contamination. No supporting quality control information is available, but standard methods were used, and there is no reason to suspect a problem with the data based on 1) an inspection of the data, 2) their environmental distribution relative to data produced by other studies, or 3) supporting technical reports. These data should be considered estimates and used only to provide an indication of the nature and possible extent of contamination.
Level 4	**Data are not acceptable for use in the cleanup decision process.** The data may have been acceptable for their original use. However, little or no supporting information is available to confirm the methods used, no quality control information is available, or there is documentation in technical reports that suggests the data may not be acceptable for use in regulatory decision-making.

provided in WAC 173-204-315 and apply to all stages of the decision process. Biological tests must be performed according to currently accepted standard protocols and quality assurance and quality control (QA/QC) procedures.

The following criteria must be met before data from biological tests may be used in the decision process:

1. Data from two acute effects tests and one chronic effects test must be available for **each** of at least three stations in the cluster. The acute tests must include the amphipod 10-day mortality bioassay and one of the following four larval mortality/abnormality bioassays:

   - Pacific oyster (*Crassostrea gigas*)
   - Blue mussel (*Mytilus edulis*)
   - Purple sea urchin (*Strongylocentrotus purpuratus*)
   - Sand dollar (*Dendraster excentricus*).

   One of the following chronic tests must be used:

   - Benthic infaunal abundance, including the major taxa Crustacea, Polychaete, and Mollusca
   - Juvenile polychaete (*Neanthes*) 20-day biomass
   - Microtox® (saline extract).

   Ecology may approve the use of an alternate test if Ecology determines, through best professional judgment, that use of the test meets the intent of Chapter 173-204 WAC and that the test has sufficient technical merit to justify departure from the tests listed above.

2. Sample collection, laboratory analysis, and QA/QC procedures must conform to Puget Sound Estuary Program (PSEP) protocols, as amended, or other methods authorized by Ecology, unless deviations from these procedures are authorized by Ecology. PSEP protocols for the acute and chronic bioassays listed above are presented in PSEP (1991a). PSEP protocols for benthic infaunal analysis are presented in PSEP (1987). These protocols are available from EPA Region 10, Office of Puget Sound, Seattle, Washington.

3. Performance standards for reference area sediments and control sediments described in WAC 173-204-315(2) must be met. These requirements are listed in Table B-3 in Appendix B and are discussed below for each test type.

   Amphipod Bioassay: The control sediment must result in less than 10-percent mortality over the test period. The reference sediment must result in less than 25-percent mortality.

   Larval Bioassays: The seawater control sample must result in less than 50-percent combined mortality and abnormality.

   Juvenile Polychaete: The control sediment must result in less than 10-percent mortality. The reference sediment must result in a mean biomass that is at least 80 percent of that found in the control sediment.

   Quantitative performance standards for benthic infaunal analysis and Microtox® are currently reserved. Qualitative performance standards for benthic infaunal analyses [as stated in WAC 173-204-315(2)(c)] are as follows:

   1. The taxonomic richness of benthic macroinvertebrates and the abundances of higher taxonomic groups shall reflect seasonality and natural physical-chemical conditions (e.g., grain size composition and salinity of sediments, water depth) in a reference area, and not be obviously depressed as a result of chemical toxicity;

   2. Normally abundant species that are known to be sensitive to chemical contaminants shall be present;

   3. Normally rare species that are known to become abundant only under chemically disturbed conditions shall be rare or absent; and

   4. The abundances of normally rare species that control community structure through physical modification of the sediment shall be similar to those observed at the test sediment site.

   Ecology's Sediment Management Unit should be consulted on a case-by-case basis to determine whether reported reference and control data for Microtox® and benthic infaunal analysis meet performance standards.

2.4 Screening Station Clusters

In this section, instructions are provided for screening station clusters. This screening will determine whether a station cluster is a station cluster of potential concern or a station cluster of low concern. Station clusters of potential concern will be evaluated during the hazard assessment, described in Chapter 3. Station clusters of low concern are returned to the station database. Stations that are returned to the database may be reconsidered for cluster identification and screening at a later date if new information becomes available.

Both chemical and biological data may be used to screen station clusters, subject to the data requirements described in Section 2.3. Either set of data can be used independently to show that the station cluster is of concern. It is anticipated that, by this stage in the data collection process, few station clusters will have the required level of biological data to perform screening.

2.4.1 Screening Using Chemical Data

Worksheet 1 (*Station Cluster Screening Using Chemical Data*) is used to screen station clusters based on chemical data. An example of a completed worksheet is provided as Figure 2-4, and a blank copy of the worksheet is provided in Appendix A. For quick reference, tables used in filling out the worksheets are provided in Appendix B. The following steps are used to complete the worksheet:

1. On the back side of the worksheet, list the stations that are part of the station cluster.

2. In the first column, list all contaminants that exceed the SQS at three or more stations in the cluster. If the chemistry data for the station cluster are contained in the database, Ecology's database manager can be requested to provide a list of the contaminants that exceed the SQS for each station. If the sediment chemistry data are from another source, the comparison is performed manually. A list of the SQS is provided in Table B-1 of Appendix B.

   IMPORTANT — The SQS for most nonionizable organic contaminants are listed in units of mg/kg organic carbon. However, many historical data are provided in units of mg/kg dry weight. To convert chemical data expressed as mg/kg dry weight to mg/kg organic carbon, the following equation is used:

WORKSHEET 1
Station Cluster Screening Using Chemical Data

Station Cluster ID: SC001
(see reverse side for list of stations)

Contaminant	3 Highest Concentrations			Average of 3 Highest Concentrations	Average Exceeds CSL?	
	1	2	3		Yes	No
1. Mercury	3.6	1.3	1.1	2.0	☒	☐
2. Benzo(a)pyrene	1,300	1,000	590	963	☒	☐
3. Fluoranthene	2,200	1,300	280	1,260	☒	☐
4. Benz(a)anthracene	1,100	710	600	803	☒	☐
5. Chrysene	1,600	1,200	990	1,263	☒	☐
6. Indeno(1,2,3-c,d)pyrene	1,500	1,000	68	856	☒	☐
7. Total benzofluoranthenes	2,500	2,500	830	1943	☒	☐
8. Phenanthrene	590	250	140	327	☐	☒
9. Di-n-octyl phthalate	8,600	2,700	350	3,883	☐	☒
10. Butyl benzyl phthalate	410	68	36	171	☒	☐
11. PCBs	410	380	330	373	☒	☐
12.					☐	☐
13.					☐	☐
14.					☐	☐
15.					☐	☐
16.					☐	☐
17.					☐	☐
18.					☐	☐
19.					☐	☐
20.					☐	☐

Station Cluster Designation:
☐ Station cluster of low concern (no averages exceed CSL)
☒ Station cluster of potential concern (at least one average exceeds CSL)

Name: John Q. Regulator   Date: 3/9/91

Figure 2-4. Example Worksheet 1.

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$$\text{mg/kg organic carbon} = \frac{\text{mg/kg dry weight}}{\text{TOC}}$$

where:

TOC = percent total organic carbon (expressed as a decimal; i.e., 1% TOC = 0.01).

If total organic carbon (TOC) data are available, this conversion should be made for each station separately, because TOC may vary significantly from station to station. Sediment chemistry data available from the database can be requested along with the TOC data for each station. When the database is used to perform the comparison between the chemistry data and the SQS, the conversion is performed automatically. Some historical data sets may not include information on TOC. For screening purposes, a TOC of 1 percent may be assumed when actual TOC data are not available.

3. List the three highest concentrations of each contaminant found in the station cluster in the columns indicated. Be sure the concentration is listed in the same units as the CSL for that contaminant (1 mg/kg = 1,000 μg/kg). The three stations need not be the same for each contaminant.

4. Calculate the average of the three highest concentrations for each contaminant and list it in the column indicated.

5. Compare the average concentration to the CSL (WAC 173-204-520) listed in Table B-1. If the average concentration is higher than the CSL, check the box labeled *Yes*. If the average concentration is lower than the CSL, check the box labeled *No*.

6. If contaminants or other deleterious substances are present within the station cluster for which no CSLs are available, list the three highest concentrations and calculate the average of the concentrations (the same as in Step 3 for the other contaminants). Check with Ecology's Sediment Management Unit for guidance on determining whether the average concentration listed is of concern. Mark the *Yes* box if the level is of concern or the *No* box if it is not of concern.

7. If *No* is checked for all contaminants, the station cluster is of low concern. If one or more contaminants are checked *Yes*, the station cluster is of potential concern. In either case, check the appropriate box under *Station Cluster Designation*.

8. Sign and date the worksheet. If the station cluster is of low concern, and biological data are available for review, proceed to the biology worksheet (Worksheet 2). If no biological data are available for review, and the station cluster is of low concern, return the worksheet to the Sediment Management Unit for filing. If the station cluster is of potential concern, keep the worksheet with the station cluster file and send a copy, along with supporting data, to the Sediment Management Unit. Proceed to the hazard assessment (described in Chapter 3).

2.4.2 Screening Using Biological Data

Worksheet 2 (*Station Cluster Screening Using Biological Data*) is used to screen station clusters based on biological data. An example of a completed worksheet is provided as Figure 2-5, and a blank copy of the worksheet is provided in Appendix A. For quick reference, tables used for filling out the worksheets are provided in Appendix B. The following steps are used to complete the worksheet:

1. On the back of the worksheet, list the stations that are part of the station cluster.

2. Check the biological data to be sure they meet all of the requirements listed in Section 2.3.2. If the biological data do not meet these requirements, use the chemistry worksheet (Worksheet 1) for screening.

3. Locate the three stations that are associated with the most severe biological effects (based on all three tests), and enter the station numbers in the left-hand column. These stations will not necessarily be the same three stations that have the highest chemical contamination.

4. The three biological tests that will be used to evaluate the station cluster should be listed in the top row. One test must be the amphipod bioassay, one must be a larval bioassay listed in Section 2.3.2, and one must be a chronic test listed in Section 2.3.2. If there is more than one larval bioassay or chronic test available, choose the one that shows the most severe biological effects at the three stations listed.

5. Compare the biological effects at these three stations with the SQS and CSL biological criteria (WAC 173-204-520) listed in Table B-2.

WORKSHEET 2
Station Cluster Screening Using Biological Data

Station Cluster ID: ____________________
(see reverse side for list of stations)

	Amphipod Bioassay	Larval Bioassay Pacific Oyster	Chronic Test Benthic Infauna	Total Tests Failed	Fail *	Pass
Station # EX001	Fails SQS ☒ Fails CSL ☒	Fails SQS ☒ Fails CSL ☐	Fails SQS ☒ Fails CSL ☒	Fails SQS 3 Fails CSL 2	☒	☐
Station # EX002	Fails SQS ☐ Fails CSL ☐	Fails SQS ☐ Fails CSL ☐	Fails SQS ☒ Fails CSL ☒	Fails SQS 1 Fails CSL 1	☒	☐
Station # EX003	Fails SQS ☒ Fails CSL ☐	Fails SQS ☐ Fails CSL ☐	Fails SQS ☐ Fails CSL ☐	Fails SQS 1 Fails CSL 0	☐	☒

* A station fails if 2 or more tests fail SQS or if one or more tests fail CSL; see Table B-2.

Station Cluster Designation:

☒ Station cluster of low concern (0-2 stations fail)

☐ Station cluster of potential concern (all 3 stations fail)

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Figure 2-5. Example Worksheet 2.

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If the biological effects at a station fail the SQS or CSL criteria, check the appropriate box(es) for that station and test.

6. Once all stations and tests have been compared with the biological criteria, add up the number of tests that each station fails and write the totals in the appropriate column. Add SQS and CSL failures separately.

7. If **either** two or more tests fail the SQS at a station **or** one test fails the CSL, the station as a whole fails. If just one or no tests fail the SQS and no tests fail the CSL, the station as a whole passes (see Table B-2). Check the appropriate box in the right-hand column for each station.

8. If all three stations fail, the station cluster is of potential concern. If one or more of the stations pass, the station cluster is of low concern. Check the appropriate box under *Station Cluster Designation.*

9. Sign and date the worksheet. If the station cluster is of low concern based on both chemical and biological data, return Worksheet 2 with the chemistry worksheet (Worksheet 1) to the Sediment Management Unit for filing. If the station cluster is of potential concern based on either chemical or biological data, keep both worksheets with the station cluster file and send a copy, along with supporting data, to the Sediment Management Unit. Proceed to the hazard assessment (described in Chapter 3).

2.4.3 Notification

Prior to initiating the hazard assessment, the site manager should notify all affected landowners, lessees, onsite dischargers, adjacent dischargers, and other potentially affected parties that the station cluster is considered of potential concern and that a hazard assessment will be undertaken.

3. HAZARD ASSESSMENT

WAC 173-204-530

3.1 Purpose of the Hazard Assessment

The purpose of the hazard assessment is to gather all existing data on a station cluster of potential concern. These data are used to further characterize the station cluster and to support site identification and site ranking. According to WAC 173-204-530(2), Ecology personnel are authorized to request any and all existing data from onsite dischargers, lessees, owners, and adjacent dischargers, including data required to:

- Determine the concentration, areal extent, and depth of sediment contamination, including the contaminants that exceed the SQS and the CSLs, the boundaries at which these standards are met, and the levels of toxicity of sediments to biological organisms
- Characterize risks to human health
- Characterize present and historical sources of contaminants to sediments within the station cluster
- Characterize habitat quality and identify sensitive biological and food resources in the vicinity of the station cluster
- Identify the locations of adjacent sediment impact zones (if any).

3.2 Data Gathering Procedures and Requirements

The hazard assessment includes collection and review of all existing data regarding a station cluster, including historical data, data that may be of lower quality than PSEP standards, and qualitative information on the area around the station cluster. It is the policy of Ecology that collection and analysis of additional samples will not be required during the hazard assessment. However, a party associated with a station cluster may, voluntarily and at their own expense, collect data during the period in which Ecology is conducting a hazard assessment. If these data are made available to Ecology staff before the hazard assessment is complete, the data should be included and reviewed as part of the hazard assessment. Completion of a hazard assessment may be delayed at the discretion of Ecology, pending completion of an important ongoing study, particularly if no other recent data of acceptable quality are available.

When available, the types of data described below should be collected during the hazard assessment to support site identification, ranking, and characterization. Different kinds of data are needed for each purpose. Some data are required for the site identification and ranking processes, and other data are optional but provide useful information for interpreting the required data and may be included for completeness. The purpose of each type of data and whether it is required or optional is included in the description below; Table 3-1 provides a data checklist for site managers.

3.2.1 Sediment Chemistry (Required)

Sediment chemistry data are collected to characterize the nature of the contamination present within the station cluster and to allow site identification and ranking. The hazard assessment focuses on surface sediment data because contamination in surface sediments is more directly related to biological and human health effects. Data on subsurface contamination are needed for remedy selection and are collected, when possible, during the hazard assessment, but may be supplemented during the cleanup study.

Sediment chemistry data should be reviewed chronologically along with historical information on sources of contaminants to the station cluster to gain an understanding of the important events and trends in contaminant loading and sediment contamination in the area. Contaminants of concern for the station cluster should be identified through a comprehensive review of all sediment chemistry data and information on

TABLE 3-1. HAZARD ASSESSMENT CHECKLIST

REQUIRED DATA

Sediment Chemistry

- ☐ The maximum concentrations of contaminants that exceed Sediment Quality Standards (SQS)
- ☐ Stations that exceed SQS and cleanup screening levels (CSL) for each contaminant
- ☐ Total area that exceeds SQS and CSL for any contaminant
- ☐ Contaminants that exceed 5 times the reference area concentrations

Contaminant Properties

- ☐ Solubility (for contaminants that exceed SQS)
- ☐ Bioconcentration potential (for contaminants that exceed SQS)
- ☐ Toxicity data (for contaminants that exceed 5 times the reference area concentrations)
- ☐ Carcinogenicity (for contaminants that exceed 5 times the reference area concentrations)

Physical Environment

- ☐ Bathymetry
- ☐ Sedimentation rate
- ☐ Grain size/habitat complexity

Biological Resources

- ☐ Shellfish beds
- ☐ Nursing, spawning, and rearing areas for salmonid and bottomfish
- ☐ Groundfish resource areas
- ☐ Eelgrass and kelp beds
- ☐ Wetlands and salt marshes
- ☐ Waterfowl and seabird nesting areas
- ☐ Wildlife refuges and sanctuaries
- ☐ Marine mammal haul-out areas

TABLE 3-1. (Continued)

REQUIRED DATA (continued)

Human Environment

- ☐ Recreational fishing and shellfishing areas, including developed access points and public beaches
- ☐ Commercial fishing and shellfishing areas
- ☐ Tribal fisheries and shellfish beds

OPTIONAL DATA

Sediment Chemistry

- ☐ Total organic carbon data
- ☐ Presence of debris

Biological Effects

- ☐ Laboratory bioassay data
- ☐ *In situ* bioassay data
- ☐ Benthic infaunal analyses
- ☐ Epibenthic or fish community data
- ☐ Histopathology data

Bioaccumulation

- ☐ Bioaccumulation data

Sources of Contaminants

- ☐ Types of sources
- ☐ Contaminants released
- ☐ Locations
- ☐ Dates of releases
- ☐ Source control/cleanup history
- ☐ Loading data

known sources. Contaminants of concern include all contaminants that exceed or have exceeded the SQS at at least one station.

The areal extent and concentrations of contaminants of concern should be identified. For ease of analysis, data collected during the hazard assessment that are not already in the database should be entered. All data entered into the database must undergo quality assurance review and validation before being entered. Validation of data entered into the database will be performed by the database manager of Ecology's Sediment Management Unit. Once the data are entered in the database, various analyses can be performed automatically, either by the database or through transfer to a GIS or PC-based tool with computational and plotting capabilities. Ecology's Sediment Management Unit can be requested to provide database-supported analyses. Activities to support site identification and ranking should be performed using the most recent data set that provides comprehensive coverage of the site, such as:

- **Identifying maximum concentrations**—The maximum concentration of each contaminant of concern within the station cluster should be identified. This information is used as part of site ranking.

- **Characterizing the pattern of criteria exceedances**—Individual stations or areas within the station cluster in which the SQS or CSLs are exceeded for specific contaminants should be identified and mapped for future reference. These stations can be identified automatically by the database.

- **Calculating the area of exceedance**—The areas of sediments that exceed the SQS and the CSLs should be calculated because this information is needed for site ranking and identification of the station cluster boundary. There are several methods that can be used to calculate area. If a GIS is available, stations and concentration data can be entered into GIS and Thiessen polygons can be plotted. Thiessen polygons, which are polygons within which each point is closer to the central station than any other station, provide a visual estimate of the area associated with each station and can be color-coded to identify areas that exceed SQS or CSLs (see Figure 3-1). The GIS uses the area within the polygons to calculate the total area that exceeds each standard. This method for estimating area assumes that the standard exceedance measured at a station extends halfway to any adjacent stations. This method can also be used with biological data.

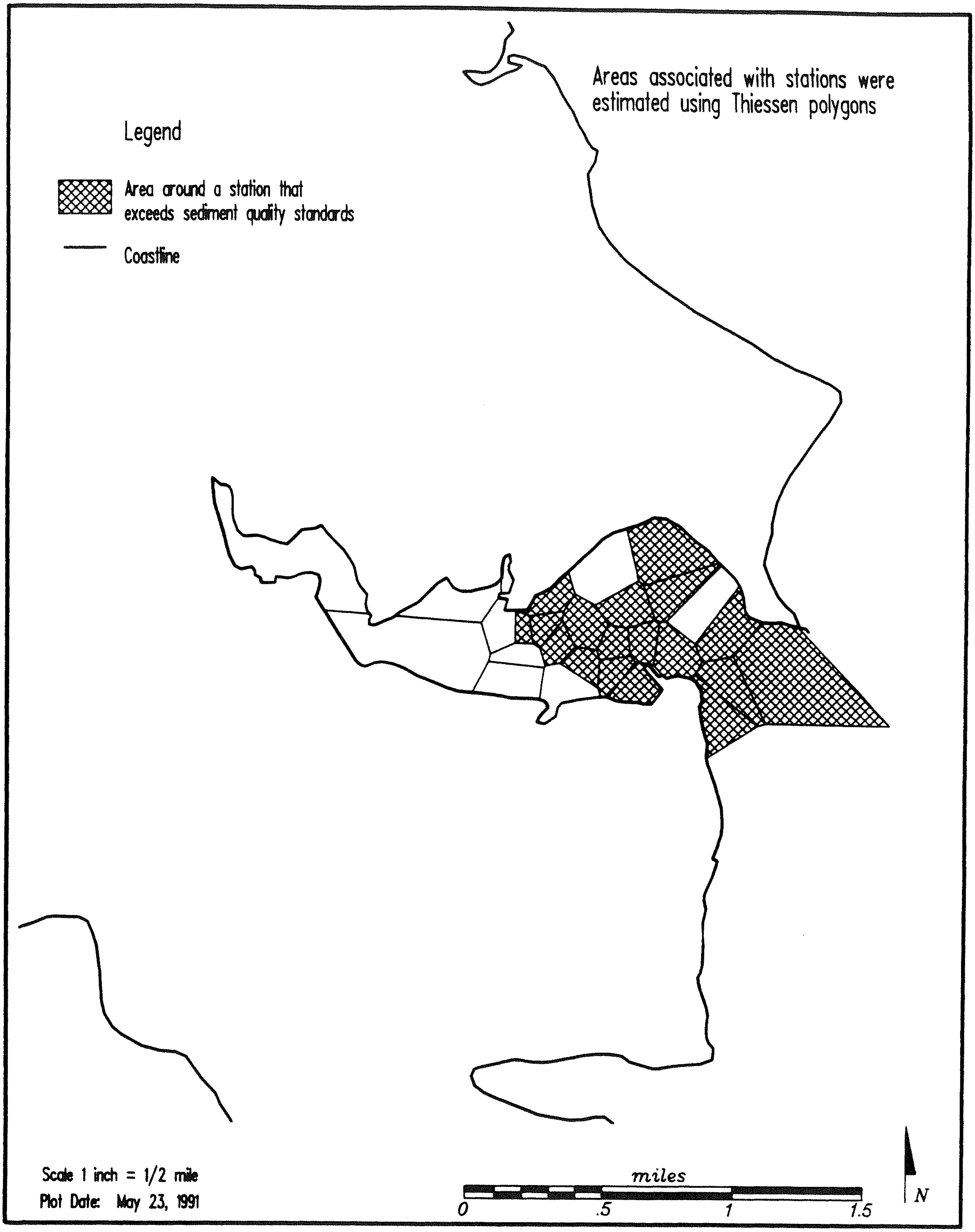

Figure 3-1. Example of GIS map showing exceedence of sediment quality standards

PC-based contouring programs, such as SURFER, can also be used to develop maps showing areas that exceed specific standards. These areas are defined by contours depicting contaminant concentrations. These contours can also be digitized into GIS and areas can be calculated automatically, or areas within the relevant contours can be calculated by SURFER or by using a planimeter. This method for estimating area uses interpolation and may result in a different estimate of area than the Thiessen polygon method. This method cannot be used with biological data.

- **Identifying human health concerns**—Areas and stations with contaminants of concern for human health that exceed 5 times the reference concentrations should be identified. This information is used as part of site ranking to evaluate potential risks to human health.

- **Performing optional evaluations**—An optional evaluation that may be performed as part of site ranking requires information on TOC and the presence of debris (such as wood chips) at the site, because the presence of these substances may adversely affect the ecological community. TOC data are available for most stations in the database.

3.2.2 Properties of Contaminants (Required)

Site ranking is, in part, based on certain properties of contaminants, such as solubility, potential for bioaccumulation, and toxicity. In addition to the sources of information listed below, much of the contaminant-specific information discussed below is tabulated in the *SEDRANK Guidance Document* (PTI 1991b). The following information should be collected to support site ranking:

Solubility

Information on the solubility of contaminants is used as part of site ranking to determine the potential for a contaminant to persist in sediments and is determined on a contaminant-specific basis. Solubility data are available in U.S. EPA (1979), the *Superfund Public Health Evaluation Manual* (U.S. EPA 1986b), and the National Library of Medicine *Hazardous Substances Data Bank* (HSDB 1991). HSDB is available online and has solubility and other data for over 4,000 contaminants.

Bioconcentration Potential

The potential for a contaminant to bioconcentrate or bioaccumulate is important for assessing its potential to cause adverse ecological and human health effects through food chain pathways. For the purposes of site ranking, the potential for bioconcentration is estimated from the octanol-water partitioning coefficient (K_{ow}). K_{ow} values for many contaminants of concern in Puget Sound can be found in PSDDA (1986a), U.S. EPA (1979, 1986b), and HSDB (1991).

Toxicity Data

Chronic and acute toxicity data are also used as indicators of the potential for a contaminant to cause adverse human health effects. Chronic toxicity data used during site ranking include oral acceptable chronic intake levels, reference doses, no observed adverse effect levels. and lowest observed adverse effect levels. These data are listed in U.S. EPA (1986b). Acute toxicity values used during site ranking include LD_{50} and LD_{LO} data for humans, rats, or mice. These data can be found in the National Institute of Occupational Safety and Health Registry of Toxic Effects of Chemical Substances, which can be accessed online.

Carcinogenicity

Carcinogenic potency factors are used during site ranking as an indicator of the potential for a contaminant to cause adverse human health effects. Current carcinogenic potency factors, and their weight-of-evidence classifications, should be obtained from the EPA Integrated Risk Information System, which can also be accessed online.

3.2.3 Physical Environment (Required)

As part of the sediment ranking system, various aspects of the physical environment are used to evaluate both the present and potential quality of a biological environment and the potential for contaminants in sediments to recover naturally. The data that should be collected to support these analyses are discussed below.

Bathymetry

The water depth at a site is used as one indicator of the potential quality of a habitat; nearshore and intertidal habitats are generally more biologically productive and diverse than deep-water habitats. Bathymetry charts for Puget Sound are available from the National Oceanic and Atmospheric Administration and are also presented for many of the urban bays in the *Puget Sound Environmental Atlas* (Evans-Hamilton 1987). Digitized bathymetric data for Puget Sound are available from the National Geophysical Data Center in Boulder, Colorado, and are compatible with GIS.

Sedimentation Rate

The sedimentation rate is used as one indicator of the potential for contaminated sediments within a station cluster to recover naturally. Sediment accumulation data for Puget Sound is presented in two major studies (Carpenter et al. 1985; Lavelle et al. 1986) and can sometimes be found in local studies performed as part of cleanup investigations in an area. For example, sediment accumulation rates were determined as part of the Superfund investigations in Commencement Bay (Tetra Tech 1987) and Eagle Harbor (CH2M Hill 1989).

Grain Size and Habitat Complexity

Habitat complexity is used to rank the potential for biological effects at a station cluster. Important factors in habitat complexity are grain size and the variation of grain size in an area. Grain-size data are available for most stations in the database. Grain-size data have also been compiled into maps by Roberts (1974) and published in Evans-Hamilton (1987).

3.2.4 Biological Resources (Required)

The biological resources in the vicinity of a station cluster provide an indication of the potential for adverse biological effects from contamination at the station cluster. Sensitive resources at and near a station cluster should be identified during the hazard assessment. Sensitive resources may include shellfish beds, fish spawning grounds, juvenile salmonid habitat, areas with groundfish resources, eelgrass and kelp beds, wetlands and salt marshes, waterfowl and seabird nesting areas, wildlife refuges and sanctuaries, and areas used by marine mammals.

Information on nearly all of these sensitive biological resources can be found in Evans-Hamilton (1987) and the biennial *State of the Sound* reports published by the Puget Sound Water Quality Authority. Additional information on the locations of many of the above resources can also be found in maps published in NOAA (1987b). Additional information on shellfish resources is presented in DSHS (1991).

3.2.5 Human Environment (Required)

Information on human activities at or near the station cluster is used to determine the potential for adverse human health effects from contamination at the station cluster. Exposure to contaminants through ingestion of contaminated fish or shellfish is the only exposure route considered in the evaluation of human health risks during site ranking. Therefore, information on the recreational, commercial, and tribal use of fish and shellfish resources is important.

General information on the locations of these areas can be found in Evans-Hamilton (1987), in *State of the Sound* reports, and in U.S. DOC (1977). Total recreational, commercial, and tribal catches are tabulated annually by the Washington Department of Fisheries. However, fish and shellfish may be caught outside of areas identified in these reports. Information from persons familiar with the site or from a site reconnaissance may be helpful in confirming area use activities. The presence of enhanced public access to resources within or near the station cluster should be noted, such as public fishing docks or popular shellfishing beaches. Information on consumption rates of recreationally caught fish in Puget Sound is presented in NOAA (1987a).

3.2.6 Biological Effects Data (Optional)

All biological effects data from bioassays, benthic surveys, and histopathologic studies that have been collected at or near the station cluster should be identified and reviewed to provide general information on potential harmful effects to aquatic life that may be related to contamination at the station cluster. These data should also be evaluated to determine whether they meet the station cluster screening criteria outlined in Section 2.3.2. If the biological data meet these requirements, and if biological data are available for the three most contaminated stations in the station cluster, the data may be used during the site identification and ranking steps.

The following data should be summarized:

- Species tested and methods of collection
- Endpoints tested

- Laboratory methods
- QA/QC information
- Results of the analyses, including an analysis of statistical significance
- Comparison of the results to biological SQS and CSLs (or elevation above reference for tests not included in the Sediment Management Standards)
- Qualitative correlations to patterns of chemical contamination
- Temporal or spatial trends in the data.

3.2.7 Bioaccumulation Data (Optional)

Bioaccumulation data are useful in assessing risks to human health through food chain pathways. Methods for predicting human health risk using bioaccumulation data are under development by Ecology. Therefore, these data are not currently used during site identification or site ranking. However, this information should be collected as part of a general review of hazards associated with a station cluster. The following information should be summarized for each data set:

- Species collected and methods of collection
- Tissues or organs analyzed
- Contaminants analyzed and methods of analysis
- QA/QC information
- Maximum concentrations and ranges of contaminant concentrations, noting differences between species
- Elevations above reference concentrations and exceedances of U.S. Food and Drug Administration action levels or tolerance limits, or risk-based criteria
- Any spatial or temporal trends observed in the data.

3.2.8 Sources of Contaminants (Optional)

Determining potential ongoing and historical sources of contaminants to the station cluster is an important aspect of the hazard assessment. Comparison of substances known to have been used, discharged, or spilled in the area to contaminants observed in sediments and biota provides information on which sources are most important, whether contamination may be ongoing, and whether all sources of contamination have been identified. The presence of certain contaminants in sediment samples (e.g., phthalates or dichloromethane) does not necessarily indicate that these contaminants are actually present in the environment; laboratory contamination may also be a factor. However, the presence of a known source of one or more of these contaminants may corroborate the sediment data.

For each source identified, the following items should be listed and discussed:

- Type of source (e.g., groundwater, storm drain, spill from vessel, or permitted discharges)
- Authorized National Pollutant Discharge Elimination System (NPDES) permit (potentially including authorized sediment impact zone)
- Substances and contaminants released to the environment
- Location of release
- The start and end dates of the release
- Source control or cleanup history
- Loading data, if available, including flow volumes, concentrations of contaminants, and measurement of conventional variables.

Useful information on potential sources can be obtained from a variety of federal, state, and local agencies. EPA Region 10 maintains an NPDES database from which relevant data, such as type of business and location of NPDES-permitted outfalls, can be summarized. Ecology's Water Quality Program maintains a similar database, the Wastewater Discharge Information System.

Ecology's Toxics Cleanup Program maintains the Site Management Information System database, which contains information on all hazardous waste sites on the MTCA list, including information on contaminants suspected or known to be onsite and the contaminant transport pathways that are important at the site. Additional source information on contaminated upland sites may be obtained from the Resource Conservation and Recovery Act and CERCLA offices of EPA Region 10. Ecology's Hazardous Waste Information and Planning Section also maintains a database of hazardous wastes generated by operating industrial facilities in Washington. Additional information on industrial facilities and on discharges to sanitary sewers and storm sewers can be obtained from local sewer utilities and public works departments.

4. SITE IDENTIFICATION

WAC 173-204-530(4)

4.1 Purpose

The purpose of the site identification is to use the information gathered during the hazard assessment to determine whether a station cluster poses sufficient hazards to human health and the environment to officially be identified as a site. Once a site is identified and placed on the state contaminated sediments site list, regulatory actions regarding cleanup may begin and parties may become liable for cleanup of the site and the costs of the investigation.

In this section, procedures for site identification are presented. Data requirements are presented for biological and chemical data used as part of site identification. Instructions and worksheets for identifying sites using biological and chemical data are provided. Biological effects data are considered most relevant for site identification purposes because they are a more direct indicator of the effects of contaminants in sediments on the environment than are chemistry data. Therefore, any biological effects data that meet the stringent requirements described in Section 4.2 are considered before sediment chemistry data. If the biological effects data alone are not sufficient to designate the station cluster as a site, chemistry data are also reviewed in combination with the biological data (if any) to determine whether the station cluster should be identified as a site.

4.2 Data Requirements

Site identification is one of the most important steps in the cleanup decision process. After the site is identified, it is publicly listed as a contaminated sediment site, and potentially liable parties (PLPs) associated with the site have legal responsibilities for site investigations and cleanup. Because site identification could result in legal obligations and substantial expense on the part of the regulated community and the agencies involved, the data requirements for site identification are more stringent than those for station cluster screening (e.g., Levels 1 or 2 on Table 2-1). The following sections present biological and chemical data requirements for site identification.

4.2.1 Biological Data

The following criteria must be met before biological tests may be used in place of sediment chemistry data:

1. Data from two acute effects tests and one chronic effects test must be available for **each** of at least three stations. The acute tests must include the amphipod 10-day mortality bioassay and one of the following four larval mortality/abnormality bioassays:

   - Pacific oyster (*Crassostrea gigas*)
   - Blue mussel (*Mytilus edulis*)
   - Purple sea urchin (*Strongylocentrotus purpuratus*)
   - Sand dollar (*Dendraster excentricus*).

   One of the following chronic tests must be used:

   - Benthic infaunal abundance, including the major taxa Crustacea, Polychaete, and Mollusca
   - Juvenile polychaete (*Neanthes*) 20-day biomass
   - Microtox® (saline extract).

   Ecology may approve the use of an alternate test if Ecology determines, through best professional judgment, that use of the test meets the intent of Chapter 173-204 WAC and that the test has sufficient technical merit to justify departure from the tests listed above.

2. Sample collection, laboratory analysis, and QA/QC procedures must be in conformance with PSEP protocols, as amended, or be comparable methods approved by Ecology, unless deviations from these procedures are authorized by Ecology. PSEP protocols for the acute and chronic bioassays listed above are presented in PSEP (1991a), and the PSEP protocols for benthic infaunal analysis are presented in PSEP (1987). These protocols are available from EPA Region 10, Office of Puget Sound, Seattle, Washington.

3. Performance standards for reference area sediments and control sediments described in WAC 173-204-315(2) must be met. These requirements are listed in Table B-3 of Appendix B and are discussed below for each test type.

   Amphipod Bioassay: The control sediment must result in less than 10-percent mortality over the test period. The reference sediment must result in less than 25-percent mortality.

   Larval Bioassays: The seawater control sample must result in less than 50-percent combined mortality and abnormality.

   Juvenile Polychaete: The control sediment must result in less than 10-percent mortality. The reference sediment must result in a mean biomass that is at least 80 percent of that found in the control sediment.

   Quantitative performance standards for benthic infaunal analysis and Microtox® are currently reserved. Qualitative performance standards for benthic infaunal analyses [as stated in WAC 173-204-315(2)(c)] are as follows:

   1. The taxonomic richness of benthic macroinvertebrates and the abundances of higher taxonomic groups shall reflect seasonality and natural physical-chemical conditions (e.g., grain size composition and salinity of sediments, water depth) in a reference area, and not be obviously depressed as a result of chemical toxicity;

   2. Normally abundant species that are known to be sensitive to chemical contaminants shall be present;

   3. Normally rare species that are known to become abundant only under chemically disturbed conditions shall be rare or absent; and

4. The abundances of normally rare species that control community structure through physical modification of the sediment shall be similar to those observed at the test sediment site.

Ecology's Sediment Management Unit should be consulted on a case-by-case basis to determine whether reported reference and control data for Microtox® and benthic infaunal analysis meet performance standards.

4.2.2 Sediment Chemistry

Sediment chemistry data used for site identification must have been collected and analyzed according to PSEP protocols (or other methods approved by Ecology), as stated in WAC 173-204-530(4). Applicable PSEP protocols include those addressing general QA/QC requirements (PSEP 1986a), measurement of conventional variables (PSEP 1986b), measurement of metals in sediments (PSEP 1989b), and measurement of organic compounds in sediments (PSEP 1989a). In addition, the chemistry data must meet QA/QC requirements equivalent to Level 1 or 2 requirements (see Table 2-1) for the contaminants of potential concern within the station cluster.

Sediment chemistry data that are less than 5 years old are preferable for use in site screening. Older data may not be representative of current conditions at the site because of various processes that may affect natural recovery. This is particularly true if the source of contamination is known or suspected to be primarily historical and the contaminant(s) of concern degrade rapidly in the environment, or if the station cluster is in an area with a high sedimentation rate. Older data may be used at the discretion of Ecology; however, if such data are used to identify sites, additional effort during the cleanup study should be placed on collecting data that are more representative of current conditions at the site.

4.3 Site Identification Procedures

Station clusters of potential concern that fail the CSL criteria are designated as sites. Station clusters that pass the CSL criteria are designated as station clusters of low concern and are returned to the database. Station clusters that are returned to the database may be reconsidered for screening and site identification at a later date if new information becomes available.

Instructions and worksheets for site identification using biological and chemical data are provided below. Each section includes an example of a completed worksheet.

4.3.1 Site Identification Using Biological Data

Worksheet 3 (*Site Identification Using Biological Data*) is used to identify sites when biological data are to be used. An example of a completed worksheet is provided as Figure 4-1. For quick reference, tables used for filling out the worksheets are provided in Appendix B. The following steps are used to complete the worksheet:

1. On the back of the worksheet, list the stations that are part of the station cluster.

2. Review the biological data to be sure they meet all the requirements listed in Section 4.2.

3. Locate the three stations that are associated with the most severe biological effects and enter the station numbers in the left-hand column. These stations will not necessarily be the same three stations that have the highest chemical contamination.

4. The three biological tests that will be used to evaluate the station cluster must be listed in the top row. One test must be the amphipod bioassay, one must be a larval bioassay listed in Section 4.2.1, and one must be a chronic test listed in Section 4.2.1. If there is more than one larval bioassay or chronic test available, choose the one that shows the most severe biological effects at the three stations listed.

5. Compare the biological effects at these three stations with the SQS and CSL biological criteria listed in Table B-2 (Appendix B). If the biological effects at a station fail the SQS or CSL criteria, check the appropriate box(es) for that station and test.

WORKSHEET 3
Site Identification Using Biological Data

Station Cluster ID: ______________

(see reverse side for list of stations)

	Amphipod Bioassay	Larval Bioassay Pacific Oyster	Chronic Test Benthic Infauna	Total Tests Failed	Fail *	Pass
Station # EX001	Fails SQS [X] Fails CSL [X]	Fails SQS [X] Fails CSL [ ]	Fails SQS [X] Fails CSL [X]	Fails SQS [2] Fails CSL [2]	[X]	[ ]
Station # EX002	Fails SQS [ ] Fails CSL [ ]	Fails SQS [ ] Fails CSL [ ]	Fails SQS [X] Fails CSL [X]	Fails SQS [1] Fails CSL [1]	[X]	[ ]
Station # EX003	Fails SQS [X] Fails CSL [ ]	Fails SQS [ ] Fails CSL [ ]	Fails SQS [ ] Fails CSL [ ]	Fails SQS [1] Fails CSL [0]	[ ]	[X]

* A station fails if 2 or more tests fail SQS or if one or more tests fail CSL; see Table B-2.

Site Designation:
- [X] Station cluster of low concern (0-2 stations fail) - attach completed Worksheet 4
- [ ] Site (all 3 stations fail)

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Figure 4-1. Example Worksheet 3.

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6. Once all stations and tests have been compared with the biological criteria, add up the number of tests that each station fails and write the totals in the appropriate column. Add SQS and CSL failures separately.

7. If **either** two or more tests fail the SQS at a station **or** one test fails the CSL, the station as a whole fails. If just one or no tests fail the SQS and no tests fail the CSL, the station as a whole passes (see Table B-2 in Appendix B). Check the appropriate box in the right-hand column for each station.

8. If all three stations fail, the station cluster is designated a site. If one or more of the stations pass, proceed to the chemistry worksheet (Worksheet 4). Check the appropriate box under *Site Designation*.

9. Sign and date the worksheet. If the station cluster has been designated a site, keep the worksheet with the site file and send a copy of the worksheet, along with supporting data, to the Sediment Management Unit. Proceed to site ranking (described in Chapter 5).

4.3.2 Site Identification Using Chemical Data

Worksheet 4 (*Site Identification Using Chemical Data*) is used to identify sites when chemical data are to be used. If, following the hazard assessment, more than one data set is available that meets the chemistry data requirements described in Section 4.2, the most recent data set that provides adequate coverage of the most contaminated areas at the site should be used. Adequate coverage is defined as any data set that provides sediment chemistry data for all contaminants of concern identified in historical data sets and for the three most contaminated stations identified for each chemical during the review of historical data. The three most contaminated stations may be different for different chemicals, particularly if there is more than one chemical class present or if there is more than one source.

An example of a completed worksheet is provided as Figure 4-2, and a blank copy of the worksheet is provided in Appendix A. For quick reference, tables used for filling out the worksheets are provided in Appendix B. The following steps are used to complete the worksheet:

1. On the back of the worksheet, list the stations that are part of the station cluster.

WORKSHEET 4
Site Identification Using Chemical Data

Station Cluster ID: SC001
(see reverse side for list of stations)

Contaminant	3 Highest Concentrations (at stations where biological CSLs are not met)			Average of 3 Highest Concentrations	Average Exceeds CSL?	
	1	2	3		Yes	No
1. Mercury	3.6	1.3	1.1	2.0	☒	☐
2. Benzo(a)pyrene	1,300	1,000	590	963	☒	☐
3. Fluoranthene	2,200	1,300	280	1,260	☒	☐
4. Benz(a)anthracene	1,100	710	600	803	☒	☐
5. Chrysene	1,600	1,200	990	1,263	☒	☐
6. Indeno(1,2,3-c,d)pyrene	1,500	1,000	68	856	☒	☐
7. Total benzofluoranthenes	2,500	2,500	830	1,943	☒	☐
8. Phenanthrene	590	250	140	327	☐	☒
9. Di-n-octyl phthalate	8,600	2,700	350	3,883	☐	☒
10. Butyl benzyl phthalate	410	68	36	171	☒	☐
11. PCBs	410	380	330	373	☒	☐
12.					☐	☐
13.					☐	☐
14.					☐	☐
15.					☐	☐
16.					☐	☐
17.					☐	☐
18.					☐	☐
19.					☐	☐
20.					☐	☐

Site Designation:
- ☐ Station cluster of low concern (no averages exceed CSL)
- ☒ Site (at least one average exceeds CSL)

Name: John Q. Regulator   Date: 3/9/91

Figure 4-2. Example Worksheet 4.

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2. Eliminate any stations from consideration for which biological data pass the CSL criteria. Place a "B" next to these stations on the back of the worksheet to identify stations that were not eliminated.

3. List all contaminants in the first column that exceed the SQS at one or more of the remaining stations. If the chemistry data for the stations are contained in the database, the database manager can be requested to provide a list of the contaminants at each station that exceed the SQS. If the sediment chemistry data are from another source, the comparison is performed by hand. A list of the chemical SQS is provided in Table B-1 of Appendix B.

   IMPORTANT — The sediment quality standards for most nonionizable organic contaminants are listed in units of mg/kg organic carbon. However, many historical data are provided in units of mg/kg dry weight. To convert chemical data expressed as mg/kg dry weight to mg/kg organic carbon, the following equation is used:

$$\text{mg/kg organic carbon} = \frac{\text{mg/kg dry weight}}{\text{TOC}}$$

   where:

   TOC = percent total organic carbon (expressed as a decimal; i.e., 1% TOC = 0.01).

   If TOC data are available, this conversion should be made for each station separately, because TOC may vary significantly from station to station. Sediment chemistry data available from the database can be requested along with the TOC data for each station. When the database is used to perform the comparison between the chemistry data and the SQS, the conversion is performed automatically. For this screening-level analysis, a TOC value of 1 percent may be assumed in the absence of station-specific TOC data.

4. From the remaining stations, list the three highest concentrations of each contaminant in the columns indicated. Be sure the concentration is listed in the same units as the CSL for that contaminant (1 mg/kg = 1,000 μg/kg). The three stations will not necessarily be the same for each contaminant.

5. Calculate the average of the three highest concentrations for each contaminant and list it in the column indicated.

6. Compare the average concentration to the CSL listed in Table B-1. If the average concentration is higher than the CSL, check the box labeled *Yes*. If the average concentration is lower than the CSL, check the box labeled *No*.

7. If contaminants or other deleterious substances are present within the station cluster for which no CSLs are available, list the three highest concentrations and calculate the average of the concentrations (the same as in Step 4 for the other contaminants). Check with Ecology's Sediment Management Unit for guidance on determining whether the average concentration listed is of concern. Mark the *Yes* box if the level is of concern or the *No* box if it is not of concern.

8. If *No* is checked for all contaminants, the station cluster is of low concern. If one or more contaminants are checked *Yes*, the station cluster is designated as a site. In either case, check the appropriate box under *Site Designation*.

9. Sign and date the worksheet. If the station cluster is of low concern, return Worksheet 4 with the biology worksheet (if used) to the Sediment Management Unit for filing. If the station cluster has been designated as a site, keep the worksheet with the biology worksheet (if used) in the site file and send copies of the worksheets, along with supporting data, to the Sediment Management Unit. Proceed to site ranking (described in Chapter 5).

5. SITE RANKING AND LISTING

WAC 173-204-540

5.1 Purpose

Following site identification, the sites are ranked and listed on the contaminated sediments site list. The purpose of site ranking is to determine the degree of hazard that a site poses to human health and the environment relative to other sites that have been or may be identified. The site list is maintained to inform the public of the cleanup sites that have been identified and to provide an estimate of their relative degree of hazard. The following sections describe the process of site ranking, site listing, and how and when sites may be delisted.

5.2 Site Ranking

Site ranking is performed by the Sediment Management Unit at Ecology, using the sediment ranking system known as SEDRANK. SEDRANK contains two separate scoring pathways, human health hazard and ecological hazard (Figure 5-1). For each pathway, several factors are considered, including 1) waste characteristics, such as concentration, toxicity, and mobility; 2) site characteristics, such as water depth, habitat complexity, and sedimentation rate; and 3) affected resources, including sensitive ecological habitats and fisheries. Each site is assigned a score based on these factors. Site ranking may be reassessed if additional information becomes available that would significantly alter the ranking.

If the site is to be cleaned up under MTCA authority, the Washington Ranking Method (WARM) may be used to rank the site for inclusion on the MTCA hazardous sites list, particularly if the site includes upland areas that are also contaminated. The sediment scoring pathway of WARM is a simplified version of SEDRANK. Alternatively, the sediment portion of the site may be considered separately and scored using SEDRANK.

SEDRANK is described in more detail in the *SEDRANK Guidance Document* (PTI 1991b) available from Ecology's Sediment Management Unit. Data collection activities and requirements to support ranking are described in Chapter 3, *Hazard Assessment*, and in the *SEDRANK Guidance Document*. Data collected for use in SEDRANK are also sufficient to score the site using the WARM sediment scoring pathway under the MTCA. The WARM sediment scoring pathway is described in an appendix to WARM and is available from Ecology's Toxics Cleanup Program.

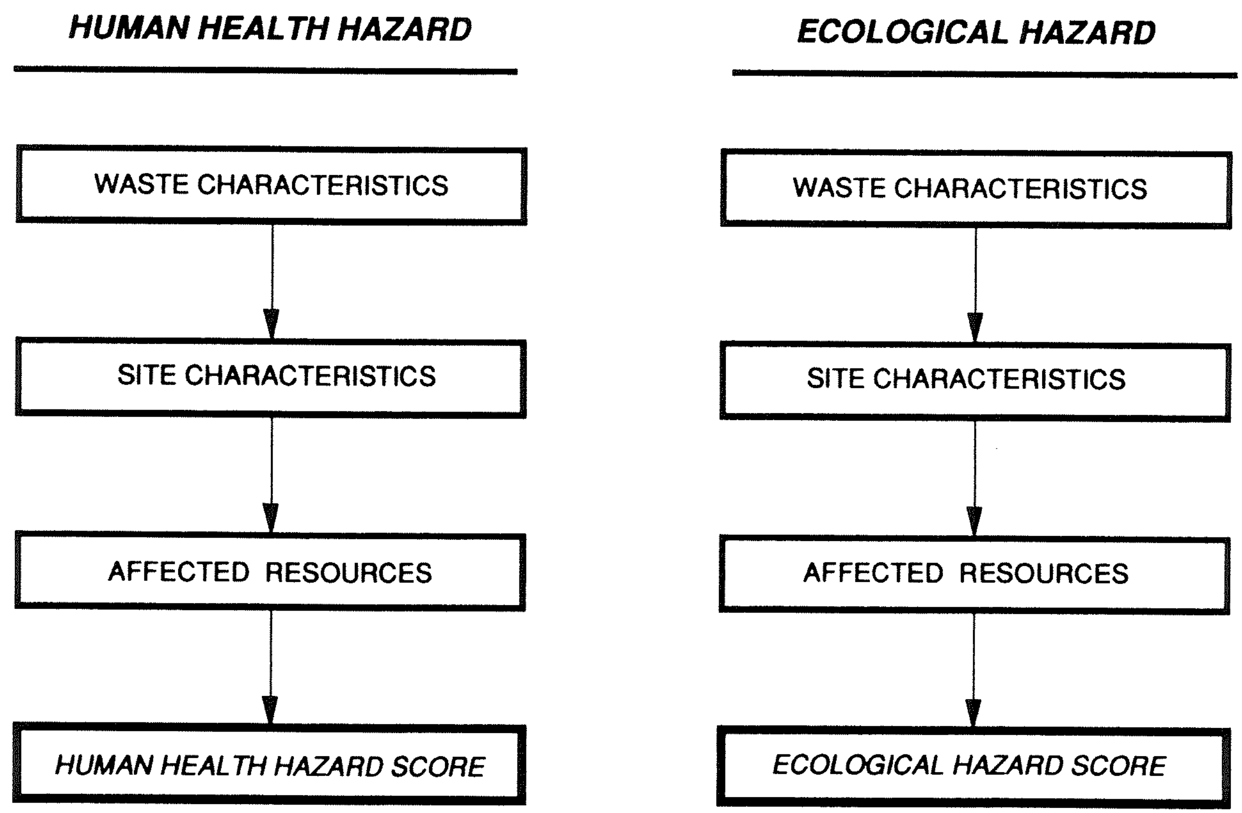

Figure 5-1. Conceptual framework of SEDRANK.

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5.3 Site Listing

After a site has been scored using SEDRANK, it is placed on the list of contaminated sediment sites maintained by Ecology's Sediment Management Unit. Sites are placed on the list in order of their score. In addition to the numerical score, the list provides information on the status of cleanup at the site. Sites from the list may be chosen for cleanup based on one or more of the following factors: their relative hazard ranking, the funding sources that are available for cleanup at the site, the technical feasibility of cleanup at the site, and opportunities for cleanup or disposal of sediments that may arise because of other scheduled activities, such as navigation dredging or nearshore construction. The list of contaminated sediment sites is published periodically and is available from Ecology's Sediment Management Unit.

5.4 Delisting

Sites may be removed from the list after a public notice and comment period under the following two circumstances:

- If all cleanup actions required by the lead agency have been completed (except confirmational monitoring), providing that compliance with the cleanup plan and cleanup standards has been achieved.

- If new information becomes available (e.g., through a cleanup study or confirmational biological testing) that indicates that the site should not have been placed on the list. To determine whether the site should remain on the list, the site identification step (described in Chapter 4) should be performed using the new information. See Chapter 4 for guidelines on when new information may be used in place of older information. As a result of this step, the site may be 1) retained on the list with its original ranking, 2) assigned a new position on the list, or 3) delisted.

Ecology may delist a site, or a party associated with a site may petition for delisting. If a party petitions for delisting, the party must provide all information necessary to determine whether the site should be delisted. Ecology may require payment in advance for review and verification of the work performed and/or the information submitted. The Sediment Management Unit retains a record of all sites that have been delisted.

6. TYPE OF CLEANUP AND DETERMINATION OF REGULATORY AUTHORITY

WAC 173-204-550

6.1 Purpose

Once sites are ranked and placed on the contaminated sediments site list, the sites may be considered for cleanup. Before beginning work at a site, two factors must be determined:

- The type of cleanup that will be performed, including determination of who will perform the cleanup
- The regulatory authority under which the cleanup will be performed.

These factors determine the agencies and private parties involved in cleanup, the administrative procedures that must be followed, and the degree of day-to-day involvement that will be required by Ecology and the site manager.

6.2 Types of Cleanup

The Sediment Management Standards provide the framework for cleanup of contaminated sediment sites within the state. The rule specifically addresses five types of cleanup: department-initiated, voluntary, incidental, partial, and federal (under CERCLA). These types of cleanup are not necessarily mutually exclusive. For example, a voluntary cleanup may only be a partial cleanup of the entire site or it may be conducted as part of an incidental cleanup. The five types of cleanup are described in the following subsections.

6.2.1 Department-Initiated Cleanups

Department-initiated cleanups are those conducted by Ecology or by liable parties as required by Ecology under the authority of Chapters 90.48 and/or 70.105D RCW. Ecology requires that all appropriate provisions of the cleanup decision process are met during department-initiated site cleanups.

6.2.2 Voluntary Cleanups

Voluntary cleanups of contaminated sediment sites are those conducted voluntarily by parties other than Ecology or EPA. Oversight and guidance in conducting voluntary cleanups are provided by Ecology to the extent possible, given resource limitations. Conducting voluntary cleanup actions in accordance with the Sediment Management Standards without agency oversight does not ensure agency approval of cleanup actions or decrease potential liability of the party. However, a voluntary cleanup may be approved by Ecology and the site may be delisted if the applicable provisions of the cleanup decision process are met and documented.

6.2.3 Incidental Cleanups

Incidental cleanups of contaminated sediment sites, or portions of sites, are those that occur as part of other state or federally permitted activities, such as navigation dredging. Like voluntary cleanups, an incidental cleanup may be approved by Ecology and the site may be delisted if the applicable provisions of the cleanup decision process are met and documented. The early coordination of incidental cleanups with Ecology is encouraged to meet the intent of the sediment cleanup decision process.

6.2.4 Partial Cleanups

Partial cleanups may occur under any of the above scenarios if discrete units within the site can be remediated separately. As discussed in Chapter 8, cleanup actions and cleanup standards may vary from one portion of a site to another. If a partial cleanup is conducted as part of a voluntary or incidental cleanup, Ecology approval will depend on whether the applicable provisions of the sediment cleanup decision process are met and documented. When a partial cleanup proceeds with Ecology oversight and guidance, cleanup of specific areas within a site may be approved if waiting for a sitewide cleanup decision would result in a net detrimental effect on the environment or human health and if the area would not become recontaminated by other areas of the site.

6.2.5 CERCLA Cleanups

CERCLA, as amended by the Superfund Amendments and Reauthorization Act, provides the federal framework for the cleanup of hazardous waste sites on land and in aquatic environments. The EPA Region 10 Hazardous Waste Division is the lead federal agency for the cleanup of CERCLA sites. When appropriate, the Sediment Management Standards will be identified by Ecology as an applicable state requirement for cleanup actions conducted by the federal government.

6.3 Determination of Regulatory Authority

The Puget Sound Water Quality Authority Act, Chapter 90.70 RCW, provided the primary direction for the development of the Sediment Management Standards. However, the primary authority for implementing and enforcing the sediment cleanup decision process is provided by the MTCA, Chapter 70.105D RCW, and the WPCA, Chapter 90.48 RCW. In the following sections, these two authorities are described, and the factors to be considered by Ecology in determining which regulatory authority to use for a given site cleanup are discussed.

6.3.1 Regulatory Authorities for Cleanup

The Model Toxics Control Act, Chapter 70.105D RCW

The MTCA, the state statute which parallels CERCLA, is designed primarily for the cleanup of sites within the state that are contaminated by hazardous substances. The MTCA includes guidelines for allocating liability for cleanup costs among parties responsible for the release of hazardous substances, and sets up a fund that may be used by Ecology for cleaning up a hazardous waste site when private funds are unavailable. The Sediment Management Standards are incorporated by reference [WAC 173-340-710(6)(d)] into the cleanup standards rule developed pursuant to the MTCA. The activities mandated by the MTCA are administered by Ecology's Toxics Cleanup Program.

The Washington Water Pollution Control Act, Chapter 90.48 RCW

The WPCA regulates discharges into state waters and other activities that affect water quality such as spills, dredging activities, and nonpoint discharges. The WPCA establishes liability for activities that affect water quality, but does not specifically provide funds for the cleanup of contaminated sediments by Ecology. Discharge permitting under the WPCA is administered by Ecology's Water Quality Program. The Sediment Management Unit is responsible for state certification of dredging and dredged material disposal actions.

6.3.2 Factors in Determining Regulatory Authority

Source of Contaminants and Media Impacted

Knowing the source of contaminants may assist in determining the appropriate regulatory authority. For example, cleanups associated with spills, dredging actions, and wastewater discharge permits would most appropriately be conducted under the authority of the WPCA, because this act directly regulates dredging and discharge permit activities in the aquatic environment. However, cleanups associated with terrestrial contamination at industrial facilities or cleanups that involve more than one environmental media would likely be conducted under the authority of the MTCA.

Area and Degree of Contamination

The size of the area requiring cleanup and the degree of contamination, including risks to human health and the environment, also affect the selection of an appropriate regulatory authority. In general, sites that cover a large area and that have high levels and large numbers of contaminants would likely fall under MTCA authority, because this statute includes stronger enforcement provisions and a mechanism for funding cleanup.

Status of Liable Parties

When selecting the appropriate regulatory authority, several factors related to the status of parties liable for contamination at a site must be considered, including:

- The number of liable parties
- The willingness of the parties to conduct cleanup
- Enforcement compliance history of the parties
- The level of communication and cooperation between the parties, including affected landowners
- Whether all the liable parties have been identified.

Cleanup under MTCA authority may be appropriate if there are many liable parties, the parties are unwilling to clean up the site, the parties are unable to cooperate with each other, and/or there are unidentified potentially liable parties. The MTCA enforcement provisions are stronger than those provided by the WPCA, allowing Ecology more flexibility in addressing complex or confrontational situations or situations in which all the liable parties cannot be located.

Level of Required Assurance

The level of assurance or complexity of agreement desired by the parties involved in a cleanup may be important in selecting the appropriate cleanup authority. For example, a landowner whose property has been impacted may want a high degree of assurance that the cleanup is conducted as planned. In general, if the level of assurance and/or complexity of agreement is low (e.g., a simple cleanup agreement) then the WPCA may be an appropriate authority. The greater and more complex the assurances needed, the greater the need for the more stringent legal provisions of the MTCA.

Public Concern

The MTCA would likely be the appropriate authority when there is a high degree of public concern or controversy over the hazards of a site and proposed cleanup methods for a site because this statute allows for (and requires) more extensive public involvement than the WPCA.

Funding Sources

The personal or corporate financial status of the PLPs may determine the appropriate regulatory authority. If state funds are required to conduct cleanup at a site, the MTCA is the appropriate regulatory authority to use because it includes a mechanism for funding site cleanups when necessary. Voluntary, incidental, or partial cleanups not requiring state funds for cleanup may be more appropriately pursued under the authority of the WPCA.

Table 6-1 lists the factors considers above and identifies the regulatory authority that would apply. In general, if the cleanup is initiated by Ecology, if the liable parties are unwilling, or if there is a need for a high level of assurance that the cleanup is performed appropriately, cleanup should be pursued under the MTCA. In contrast, if most of the conditions listed under the WPCA apply, then this authority should be used. In all other cases, the appropriate authority will need to be selected on a case-by-case basis using best professional judgment.

TABLE 6-1. FACTORS IN DETERMINING REGULATORY AUTHORITY

Water Pollution Control Act	Model Toxics Control Act
Contaminated sediments only	Multimedia contamination
Small site	Large site
Low levels of contamination	High levels of contamination
Few liable parties, all identified	Many or unknown liable parties
Liable parties willing to conduct cleanup	Liable parties unwilling to conduct cleanup
Low assurance required	High assurance required
Little public concern	High public concern
Voluntary cleanup	Cleanup initiated by Ecology

7. CLEANUP STUDY

WAC 173-204-560

7.1 Purpose

Once the regulatory authority is chosen, work at the site may begin. The first activity to occur at the site is the cleanup study. The purpose of the cleanup study is to collect, develop, and evaluate sufficient information to delineate site boundaries and site units, to select cleanup standards for the site or site units, and to select cleanup actions for the site or site units. The study should include data needed to identify 1) the vertical and horizontal distribution and magnitude of contaminants; 2) the potential for migration of contaminants beyond the site; 3) the potential for exposure of humans, aquatic biota, and wildlife to contaminants at the site and the risks from such exposure; and 4) information needed to select and design cleanup actions for the site.

7.2 Cleanup Study Plan

The cleanup study plan consists of four components:

- The work plan
- The public information and education plan
- The sampling and testing plan, including a quality assurance plan
- The health and safety plan.

The cleanup study plan is reviewed and approved by the Ecology or EPA site manager before work begins at the site. The public and affected landowners must be given an opportunity to comment on the plan. These plans may be combined with other documents to fulfill the requirements of other state and federal laws (e.g., MTCA or CERCLA remedial investigation and feasibility study work plans and reports, or a SEPA environmental impact statement).

Suggested contents of each of these plans are described in the following sections.

7.2.1 Work Plan

The work plan for the cleanup study provides information on the goals of the cleanup study, activities that will be performed, how the data will be used, what types of conclusions will be reached, who will perform the tasks, how the tasks will be managed, and what the schedule and budget will be. The following paragraphs outline suggested sections for the work plan.

Introduction

The introduction should clearly explain why the cleanup study is being performed and define the objectives of the study. This section should include general site information, such as the project title; the name, address, and phone number of the project coordinator; and a legal description of the cleanup site.

Summary of Existing Information

This portion of the work plan should provide a review of each category of information that was collected on the site during the hazard assessment. The summary should include information on site history, past and present sources of contamination to the site (including a list of owners and operators of sources), and summaries of the physical, chemical, biological, and risk assessment data. A map or maps of existing site conditions should be included, showing the site boundary, areas where individual contaminants exceed the SQS and minimum cleanup levels (MCULs), surface and subsurface topography, surface and subsurface structures, utility lines (if known), navigational lanes, and the locations of historical and ongoing sources of contaminants to the sediments. Preliminary estimates of the area and/or volume of contaminated sediments should also be provided.

This section should discuss the data quality, coverage, and how well data represent current conditions and should identify data gaps or areas where data quality could be improved. The information included in this section forms the basis of the field investigations that are described later in the work plan.

Project Administration

This section should provide information on task management and quality control, including the roles of various agencies and oversight of contractors, subcontractors, and laboratories that will be used.

Public Information and Education Plan

This section should present a plan to provide coordinated and effective public involvement during studies and cleanup activities at the site. The public information and education plan is described in WAC 173-204-560 and should include:

- Plans for providing public notice and comment periods, the length of comment periods, and the locations of public notice
- Locations where information about the site will be available to the public, such as libraries and community centers
- Methods that will be used to identify public concerns, such as public meetings, questionnaires, and interviews
- Methods that will be used to provide information to the public

- Public participation requirements of other federal, state, or local laws and how they will be addressed
- Procedures for amending the public involvement plan.

Field Investigations and Other Information Collection Activities

This section of the work plan should describe the field investigation and other information collection activities that will take place during the cleanup study. The rationale and goals of each activity should be identified. General information on field activities is provided in the work plan; specific details of sampling and analytical methods to be used are provided in the sampling and testing plan.

The following data collection activities may be included as part of the cleanup study, depending on the scope of the investigation and complexity of the cleanup site. Particularly for smaller sites, it may be possible to obtain certain categories of information from the literature (e.g., information identified in the first three bullets and the last three bullets listed below). In other cases, sufficient information will have been collected during the hazard assessment on particular aspects of the site. Finally, the scope of the field investigations that are conducted will depend heavily on the complexity of the site, the potential for uncharacterized hazards to human health and the environment, whether the source(s) of contamination have been identified, and the types of cleanup action that are contemplated for the site. For example, chemical contamination in bulk sediments and contaminant mobility in sediments need only be characterized if dredging and aquatic disposal is a likely cleanup action for a site or site unit.

- **Physical properties of surface water and sediments**— Significant hydrologic features of the surface water environment should be characterized, such as surface water drainage patterns, discharge points and flow rates, currents and tidal effects, basin geomorphology, areas of sediment erosion and deposition (including estimates of sedimentation rates), and actual or potential contaminant migration routes into or away from the site.
- **Geology and groundwater hydrology**—The subsurface geology and groundwater hydrology of sediments and upland areas associated with the site should be investigated to determine sediment and soil types, groundwater flow paths and rates, groundwater gradient, and groundwater discharge areas.

- **Climate**—Aspects of the regional and local climate that could affect the movement of groundwater, surface water, sediments, or other sources of contaminants should be identified, such as seasonal patterns of rainfall, frequency of significant storm events, and prevailing wind direction and velocity.

- **Chemical contamination of surface water and sediments**—Sufficient surface water and sediment sampling should be included to adequately characterize the areal and vertical distribution and concentrations of contaminants. Additional properties of sediments that affect toxicity and habitat quality, such as grain size and TOC, should be determined. Sampling should be performed with sufficient density of stations to allow contouring of contaminant concentrations and accurate determination of boundaries and depths at which the SQS, MCULs, and a range of potential cleanup levels are met.

  This study component is necessary to 1) distinguish between areas that will require active remedial action from areas that may be expected to recover naturally, 2) accurately determine the area or volume of sediments that will require remediation, and 3) support an assessment of the current status of source control. This investigation will also provide a baseline for post-remedial action monitoring.

- **Toxicity of sediments**—Acute and chronic sediment toxicity testing using bioassays and/or benthic infauna analysis may be performed to confirm the results of chemical tests and to account for the effects of multiple chemical contaminants. Additional studies, such as measures of abundance and diversity, *in situ* bioassays, bioaccumulation studies, and histopathology studies, may also be performed to assist in determining the impact of contaminants in sediment on the biological community near the site.

- **Chemical contamination in bulk sediment**—Chemical contamination in bulk sediments should be characterized using composite samples, chosen to be representative of areas that could be dredged as part of a cleanup action. This investigation is needed to describe the nature of contaminants in sediments that could be disposed of in aquatic, nearshore, or upland disposal sites. Characterization of bulk sediments may be confined to areas targeted for removal and may not be needed in areas where sediment is expected to remain in place or be capped.

- **Contaminant mobility in sediment**—Elutriate, column leaching, and column settling tests should be performed on sediment samples targeted for removal. This study component is needed to provide information on the behavior of contaminants during potential dredging activities and information needed for the design of confinement structures.

- **Fate and transport and natural recovery considerations**—The measurement of certain additional analytes or parameters may be appropriate if natural recovery or fate and transport analysis are used to select cleanup levels for the site. Sediment dating (e.g., ^{210}Pb measurements), sediment chronologies, and dredge horizon evaluations can be used to assess sediment accumulation and mixing. Contaminant characteristics relevant to fate and transport include species distribution, susceptibility to degradation or transformation, degree of particle association, and particle characteristics.

- **Land use**—Information should be collected concerning present and proposed uses and zoning of shoreline areas near the site and beneficial uses of the water body associated with the site, including recreational use and recreational, commercial, or tribal fisheries or shellfisheries near the site.

- **Natural resources**—Information should be collected on natural resources at or near the site that could be potentially exposed to contaminants at the site, including habitat types, sensitive ecosystems, plant and animal species, and wetlands or other regulated areas near the site.

- **Source investigations**—Sufficient information should be collected on all sources of contaminants to the sediment to allow a determination of what source control activities must be performed to ensure the long-term success of sediment remediation. The location, quantity, areal and vertical extent, concentration, and sources of wastes and other contaminant discharges to the sediment should be determined. In addition, the physical and chemical characteristics and the biological effects associated with effluent sources should be determined. Finally, necessary source control actions, the status of source control activities, and a potential time frame for control of permitted and unpermitted sources should be identified.

Data Management and Analysis

This section should describe how data collected during field investigations will be managed and analyzed. Data reduction, validation, and quality assurance techniques should be described. The analysis of data should be described, including statistical techniques used to analyze data, methods used to map and calculate areas and volumes of contaminated sediments, and a description of databases, computer programs, or models used in the analysis or plotting of data. A short description of the types of analyses that will be performed and the products of each analysis should be presented.

Human Health Risk Assessment

This section should describe the techniques that will be used to perform human health risk assessments using the data collected during the hazard assessment and cleanup study. All equations, assumptions, and references for toxicity data should be provided. This section should describe how the field investigations will support the human health risk assessment and identify any additional data gathering that will be needed. A preliminary conceptual site model, describing contaminants, contaminant transport pathways in the environment, routes of exposure, and receptors, should be developed and presented in the cleanup study work plan.

Applicable Laws and Development of Cleanup Standards

This section should present the methods and sources of information that will be used to identify applicable laws and criteria and the methods that will be used to develop proposed cleanup standards. This analysis may range from a simple identification of Puget Sound Dredged Disposal Analysis requirements for dredging operations to a full-scale analysis of applicable or relevant and appropriate requirements (ARARs) for MTCA or CERCLA sites. A preliminary evaluation of potential site units, if any, should be presented, along with a description of the criteria used to separate the site into final site units after the cleanup study is complete (see Chapter 8 for a discussion of site units and cleanup standards). These analyses should be performed during the cleanup study to support the evaluation of cleanup action alternatives.

Cleanup Action Alternatives

This section should present the methods that will be used to develop and evaluate the cleanup action alternatives for the site. A preliminary list of technologies to be considered in developing cleanup action alternatives should be presented, and the method that will be used to screen the technologies and combine them into cleanup action alternatives should be described. A separate set of cleanup action alternatives may be developed for each site unit. Finally, the criteria that will be used to screen and evaluate the cleanup action alternatives should be described. The evaluation of cleanup action alternatives is discussed in Chapter 9. Typical cleanup action alternatives are presented in Appendix D.

Proposed Contents of Cleanup Study Report

This section should provide a description of what will be included in the cleanup study report and identify any interim deliverables that are required. The contents of the cleanup study report are described in Section 7.3.

Schedule and Budget

This section should include the schedule for activities described in the cleanup study plan and the budget required to perform the activities (if the cleanup study is a voluntary action, the budget may be omitted).

7.2.2 Sampling and Testing Plan

The sampling and testing plan may be presented as an appendix to the work plan or as a second volume. The sampling and testing plan addresses the sampling, testing, and recordkeeping activities that will take place in conjunction with field activities performed during the cleanup study. The sampling and testing plan generally includes the following components:

- An overview of the proposed field sampling program, including scheduling requirements
- Detailed descriptions of sampling tasks, including the type, number, and location of samples to be collected; depths of samples; samples to be composited; and the dates that samples will be collected
- Sampling methods, including a description of positioning methods, sampling gear and operation, criteria for sample acceptance, compositing procedures, sample containers and handling procedures, and observations, testing, or analyses that will be performed in the field

- Records that will be kept and recordkeeping procedures, in conformance with WAC 173-204-610
- Identification of sampling personnel
- Standard operating procedures
- Methods of chemical analysis and biological testing that will be used and the laboratories at which the analyses and testing will be performed
- A quality assurance plan, containing descriptions of project and quality assurance responsibilities; quality assurance objectives; sample custody procedures; instrument calibration techniques; use of reference and standard materials; frequency of calibration; use of spikes, blanks, replicates, and control samples; required quality assurance audits and reports, including frequency; preventive maintenance schedules; routine procedures used in data validation; and corrective actions.

All sampling and testing procedures should be in conformance with the Puget Sound protocols (PSEP 1986a,b,c, 1987, 1989a,b, 1991a) as amended or other methods approved by Ecology. Data quality requirements should conform to Level 1 (see Table 2-1).

7.2.3 Health and Safety Plan

The health and safety plan covers all aspects of worker safety while employees are engaged in cleanup study activities. The health and safety plan should meet the requirements of the Occupational Safety and Health Act (29 CFR 1910) and the Washington Industrial Safety and Health Act (Chapter 49.17 RCW). At a minimum, the following contents should be included:

- Description of tasks to be performed
- Key personnel and responsibilities
- Chemical and physical hazards associated with the site, including potential contaminants and chemicals used during the cleanup study, hazards associated with these substances, physical hazards associated with shipboard and land-based sampling activities, heat and cold stress, locations of subsurface utilities and obstructions on the site, falling hazards, and confined spaces

- Safety and health risk analysis for each task and operation
- Air monitoring plan, including ambient air monitoring, personal monitoring, monitoring equipment, and use and calibration of monitoring equipment
- Personal protective equipment that will be used for site tasks, and criteria for upgrading and downgrading protective equipment based on monitoring and changes in ambient contaminant levels or other site hazards
- Work zones, including control zone, decontamination zone, and exclusion zone, and the methods used to demarcate these areas
- Decontamination procedures for personnel, protective equipment, and sampling equipment
- Procedures for disposal of contaminated media and equipment
- Safe work practices, including operation of sampling equipment and general site safety
- Standard operating procedures, including fit tests for respirators
- Contingency plan, including evacuation procedures and criteria, emergency phone numbers and addresses of hospitals, and maps showing routes to hospitals
- Personnel training requirements, including health and safety training courses and site briefings
- Medical surveillance program
- Recordkeeping procedures.

7.3 Cleanup Study Report

The cleanup study report describes the results of all data collection activities performed during the cleanup study and synthesizes this information with the data collected during the hazard assessment, if appropriate. The cleanup study report should analyze the data and evaluate cleanup alternatives in sufficient detail to support the selection of cleanup levels and cleanup actions for the site or site units. At a minimum, the following contents should be included:

- Site description, including operational and regulatory history, contaminants of concern, location, and detailed site maps (plan and cross-section views)
- A description of the hydrology and geology of surface water, groundwater, sediment, and upland areas associated with the site, including hydrogeologic cross sections and water table contour maps (plan and cross-section views)
- An evaluation and analysis of all contaminant data from the hazard assessment and cleanup study, including sampling and testing methods, concentrations contour maps (vertical and horizontal), biological effects data, discussion of historical and ongoing sources, potential for contaminant migration, potential for natural recovery, and other pertinent data for environmental media at the site
- Discussion and results of the human health risk assessment
- Discussion of applicable laws and relevant guidelines
- Identification and discussion of proposed site units
- Description of technologies that were reviewed as part of the development of cleanup action alternatives, the results of screening of the technologies, and the cleanup action alternatives that were identified for the site or site units
- Development of proposed cleanup standards for the site or site units
- Evaluation of the cleanup action options and identification of the preferred cleanup action option(s)
- Appendices containing all sampling logs and other pertinent logs

- Appendices containing the results of all physical, chemical, and biological testing, including QA/QC reviews, discussion, and recommendations
- An appendix describing the implementation of the public education and information plan
- An appendix describing the implementation of the health and safety plan
- An appendix containing photographs, slides, and public information materials.

NOTE TO USERS

The Sediment Management Standards (SMS) (Chapter 173-204 WAC) require that site cleanup standards be developed taking net environmental effects, cost, and technical feasibility into consideration. Chapter 8, Selection of Cleanup Standards, contains a section entitled "Procedures for Developing Cleanup Standards", which describes the procedures for selecting site cleanup standards. The Department of Ecology (Ecology) is currently examining the utility of the weighing and balancing methods described in this chapter for determining specific cleanup standards.

The SMS allow for the development of specific cleanup standards between the cleanup objective (sediment quality standards) and the upper regulatory limit (minimum cleanup level). The weighing and balancing methods in Chapter 8 may be used to arrive at and systematically evaluate the sensibility of proposed site specific cleanup standards. These methods are general in nature in this version of the Sediment Cleanup Standards User Manual and will be developed in more detail in future versions of the document. At this time Ecology does not prescribe one specific method.

To-date, a policy concern has been expressed by members of the Sediment Management Standards Implementation Committee, Ecology's external advisory group, regarding an assumption about the method for identifying significant cost differences, found in the Chapter 8 Screening Level Analysis section. The comment stressed that cleanup actions are often undertaken by public entities such as cities, ports, school districts and fire districts, and that these entities should not be fiscally measured in the same way as private businesses.

Ecology acknowledges and appreciates this comment. In using this chapter please note that none of the weighing and balancing methods have been developed in detail, or are mandated by Ecology. We hope to develop specific cost valuation methods as we gain experience. Recommended changes to this chapter will be incorporated in the January 1993 revision of this document.

8. SELECTION OF CLEANUP STANDARDS

WAC 173-204-570

8.1 Introduction

Once the cleanup study has been performed, cleanup standards for the site can be developed. The cleanup objective for all sites, as stated in WAC 173-204-570, is to eliminate adverse effects on biological resources and significant health threats to humans from contaminants in the sediments. This narrative sediment cleanup objective corresponds to the numerical SQS for Puget Sound listed in WAC 173-204-320 through 173-204-340. Cleanup standards for individual sites or site units are set at concentrations whose upper limits are defined by MCULs (to be achieved within 10 years of cleanup) and whose lower limits are defined by the SQS (to be achieved at the time of cleanup). SQS and MCULs are shown in Table B-1 (chemical criteria) and Table B-2 (biological criteria) of Appendix B. The cleanup standards should be as close as is practicable to the SQS, but in no case higher than MCULs. "Practicable" is defined as "able to be completed in consideration of environmental effects, technical feasibility, and cost." Cleanup standards must also meet all legally applicable federal, state, and local requirements.

The cleanup study should be nearing completion before cleanup standards are proposed for a site. The first step in determining cleanup standards is to determine whether the site will be divided into site units. Section 8.2 discusses methods for identifying effective site units. To address cost and technical feasibility, areas and volumes requiring remediation must have been estimated and preliminary screening of cleanup action alternatives performed (see Chapter 9) for each site unit. The next step is to balance the considerations of net environmental benefits, cost, and technical feasibility. This step is discussed in Section 8.3. Ecology will make the final choice of cleanup standards.

8.2 Delineation of Site Units

A site unit is an area within a cleanup site that may be remediated separately from other areas of the site and/or may have different cleanup standards. The decision to divide a site into site units is based on physical, chemical, and biological factors that affect the cleanup action alternatives that are practicable, the cost of the cleanup action alternatives, the environmental benefits of restoration, and the environmental impacts during cleanup. Each of these factors is discussed below, followed by an example illustrating the application of these factors in identifying site units.

8.2.1 Physical Factors

Physical factors at a site, such as structures, water depth, and sediment dynamics, may influence the range of cleanup action alternatives that are available in different areas of the site. Areas containing structures such as piers, riprap, and bulkheads are potentially more difficult to remediate because these structures may interfere with equipment used in dredging and capping sediments. Conversely, these structures sometimes provide physical support for nearshore fill alternatives. Underground structures such as bridge supports, sewer lines, gas lines, and telephone wires can also limit dredging alternatives. Other physical debris, such as logs or sunken metal debris, may need to be removed before dredging can be performed.

Water depth is also an important factor affecting the technical feasibility of certain cleanup action alternatives. For example, dredging alternatives are effectively limited to depths of 200 feet or less. Alternatives that include habitat mitigation may be most appropriate for intertidal or nearshore areas. Finally, navigation lanes or small ship and boat traffic passing through the site may preclude the use of alternatives that include sediment caps.

An additional factor that should be considered when developing site units is the depositional or dispersive nature of the site. Dispersive or erosional environments with high-velocity currents or turbulence (either natural or created by ship traffic) are less appropriate candidates for capping than nondispersive areas. Depositional environments may allow capping, but may also interfere with habitat mitigation by altering the shape of the shoreline or by depositing fine particles onto coarser-grained substrate.

8.2.2 Chemical Factors

At an otherwise uniform site, differing levels of chemical contamination may require different remedial alternatives. Isolated areas of high contamination may be actively remediated (possibly using treatment), while larger surrounding areas of low contamination are allowed to recover naturally. Areas that are chosen to be actively remediated may also be based on chemical concentrations associated with unacceptable risks to human health or the environment. In addition, design requirements for disposal areas may vary depending on the level of contamination in the sediments.

8.2.3 Biological Factors

Biological resources within the site are important considerations for identifying site units. Certain habitats and biological resources such as eel grass beds and rocky bottom habitats may be very slow to recover or may not be completely restorable. In these areas, the environmental costs may outweigh the environmental benefits of cleanup. After considering net environmental benefits, these areas may be left to recover naturally, rather than impacting them through active remediation.

Other areas that may recover quickly or can be restored to their original state may be considered for active remediation or habitat restoration. In addition, areas in which sensitive biological resources or humans are more likely to be exposed to high levels of contaminants may be remediated differently from those areas where biological or human exposure is less likely. For example, areas that provide habitat for juvenile salmonid prey or areas where humans come into physical contact with sediments might require special attention.

8.2.4 Example of Site Unit Identification

Figure 8-1 shows an example of a relatively complex site at which division of the site into site units would be appropriate. Site Unit #1 is a nearshore area under and around a pier for which access is difficult. Site Unit #2 is a navigation lane, in which capping alternatives would not be feasible. Site Unit #3 is a nearshore environment with a thriving kelp bed, in which capping or dredging alternatives may cause significant long-term environmental impacts. Site Unit #4 is soft-bottom, subtidal habitat between 20 and 200 feet deep, which could be considered the baseline condition for sediment sites and does not have special restrictions on cleanup alternatives.

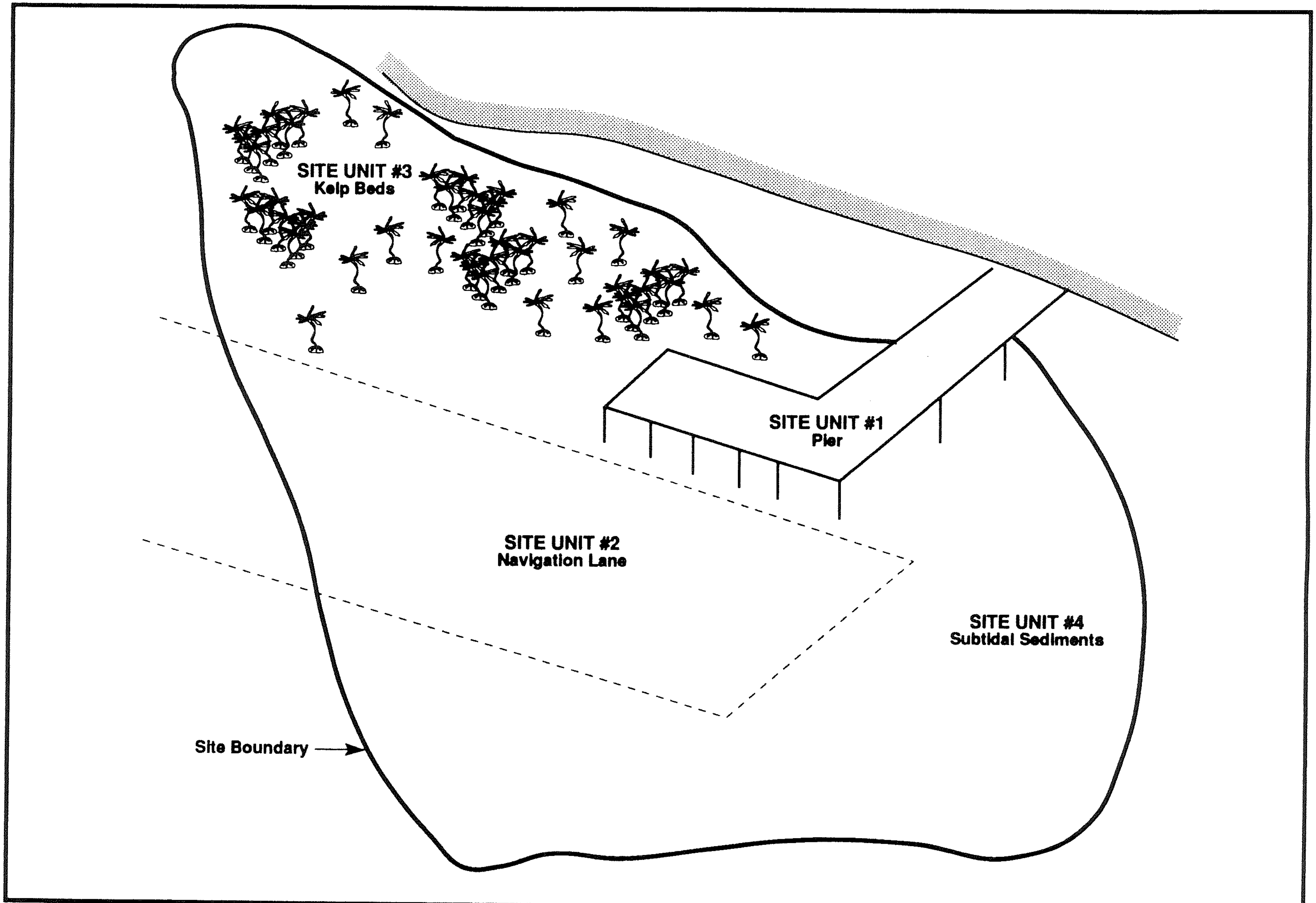

Figure 8-1. Example of site units.

8.3 Procedures For Developing Cleanup Standards

Site-specific cleanup standards are developed using a three-step process. First, information from the cleanup study is analyzed to determine the potential for natural recovery and the volumes or areas of sediment that require cleanup. Second, the factors affecting the net environmental benefits, cost, and technical feasibility of the full range of cleanup standards are identified. Finally, net environmental benefits, costs, and technical feasibility are weighed to determine an optimal cleanup standard within the possible range of standards. These steps are described in the following sections.

8.3.1 Analysis of Information from the Cleanup Study

Figure 8-2 shows the process for developing a cleanup standard for a site or site unit. First, the potential for natural recovery for each contaminant at the site is determined using procedures such as those described in Appendix C. The potential for natural recovery is important because it defines the upper end of the range of possible cleanup standards. The most stringent cleanup standard that could be chosen is the SQS, to be met immediately after cleanup (i.e., at time zero; designated as SQS_0). The least stringent cleanup standard that could be chosen is the minimum cleanup level, to be met in 10 years (designated as $MCUL_{10}$). $MCUL_{10}$ is the numerical concentration to which sediments must be cleaned up to now to reach the MCUL in 10 years. This concentration for each site is determined through a site-specific analysis of natural recovery. For example, if it is determined that, for benzene, the concentration in 10 years will be 10 percent of the initial concentration, then the $MCUL_{10}$ would be set at 10 times the MCUL.

The range of possible standards is illustrated geographically in Figure 8-3. The $MCUL_{10}$ represents the least stringent cleanup standard that could be chosen and corresponds to the smallest area (or volume) of sediments that must be cleaned up. The SQS_0 represents the most stringent cleanup standard and corresponds to the largest area of sediments that must be cleaned up. Intermediate between these two extremes are the SQS_{10} and the $MCUL_0$. If natural recovery is slow and/or the MCUL is much higher than the SQS, the SQS_{10} may be a more stringent standard than the $MCUL_0$. Conversely, when natural recovery is relatively rapid and/or the MCUL is very close to the SQS, the $MCUL_0$ may be a more stringent cleanup standard than the SQS_{10}. These cases are illustrated in Figure 8-3(a) and (b), respectively. For some chemicals, the SQS and the MCUL are the same. For these chemicals, the possible range

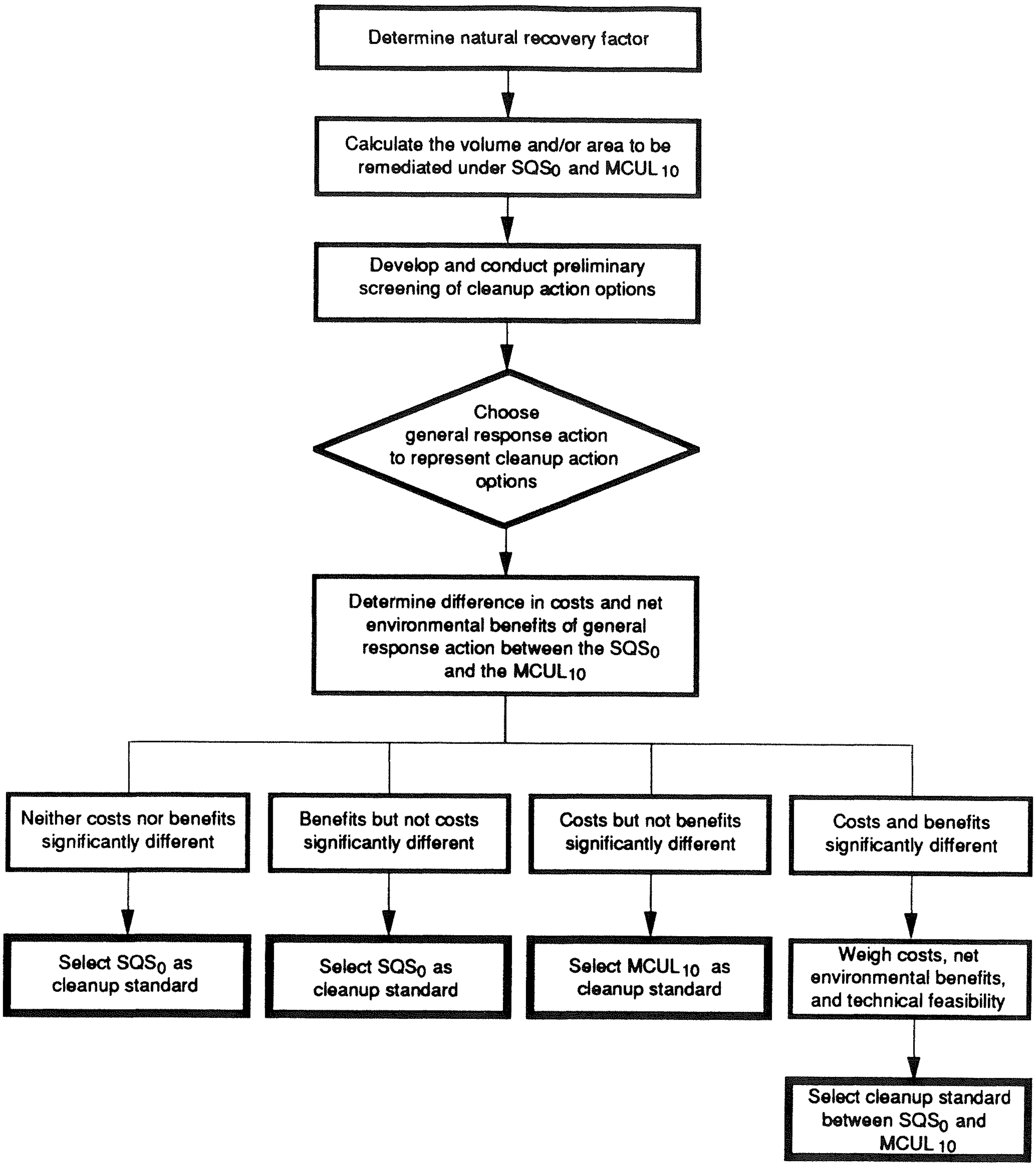

Figure 8-2. Development of cleanup standards for a site or site unit.

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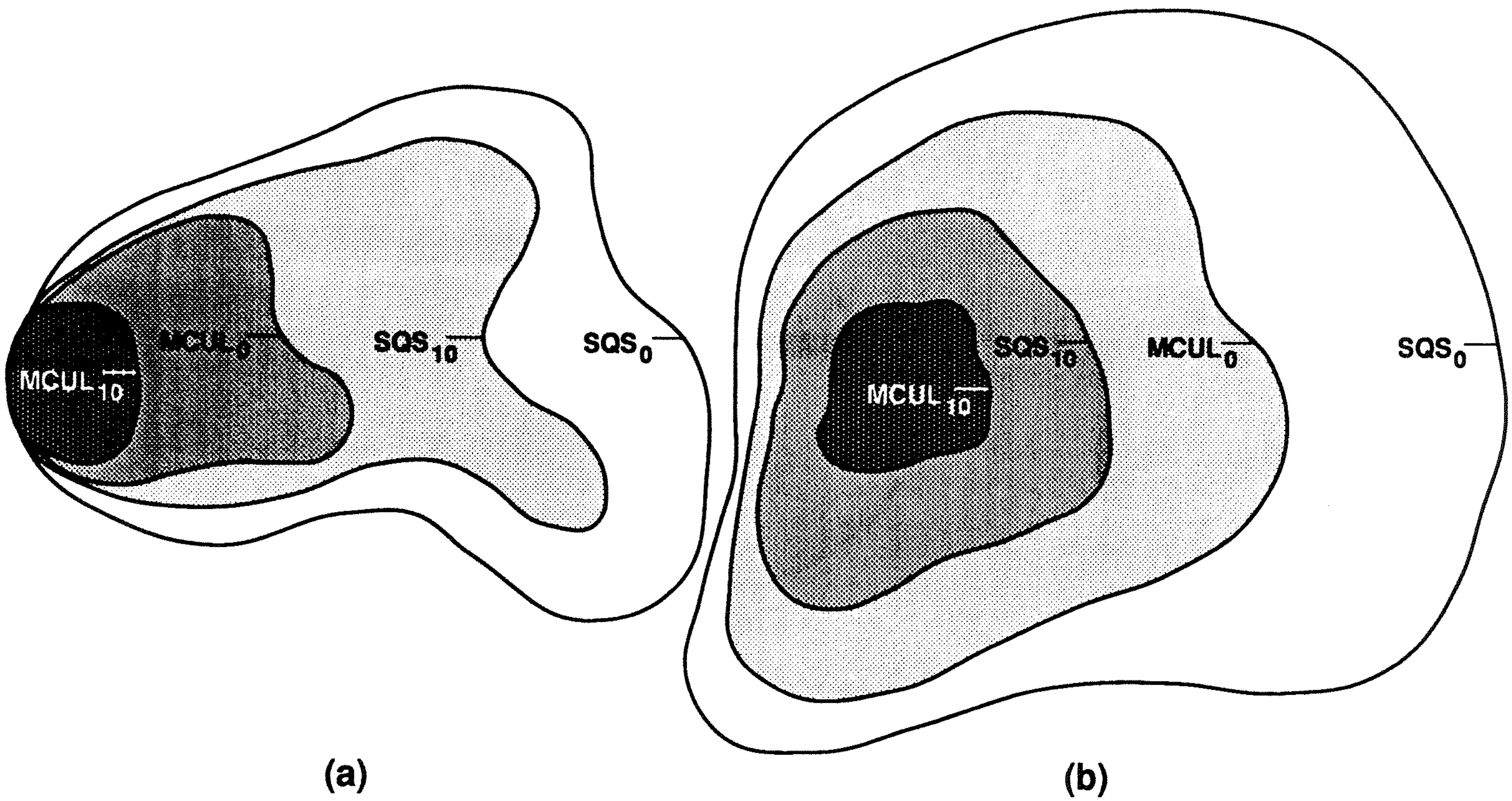

Figure 8-3. The range of possible site-specific cleanup standards.

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of cleanup standards is defined by the $SQS/MCUL_0$ at the lower end and the $SQS/MCUL_{10}$ at the upper end.

Once the possible range of site-specific cleanup standards (SQS_0 to $MCUL_{10}$) has been determined for each contaminant, the areas and volumes of sediment exceeding each of these two levels must be determined. These areas and volumes are used to calculate the cost difference between cleaning up to the lowest and the highest alternative standards. The areas associated with SQS_0 and $MCUL_{10}$ are also used, as part of a screening-level analysis, to estimate the environmental benefits associated with cleanup to each of these levels.

8.3.2 Factors Affecting the Choice of Site-Specific Cleanup Standards

WAC 173-204-570(4) mandates the consideration of net environmental benefits, cost, and technical feasibility in selecting a site-specific cleanup standard within the possible range of cleanup standards. In this section, the components of each of these three considerations are described, and the manner in which they affect the development of site-specific cleanup standards is discussed.

Net Environmental Benefits

Environmental benefits are defined as the short-term and long-term environmental and human health benefits resulting from a cleanup action. The term "net environmental benefits" means the environmental benefits resulting from a cleanup action minus the short-term and long-term impacts to the environment and human health that also result directly from the cleanup action. Net environmental benefit is therefore a measure of the actual benefits to be gained from cleanup of a site, considering both the positive and negative effects of cleanup on human health and the environment. The net environmental benefit may be either positive or negative, depending on whether the benefits of cleanup outweigh the impacts of cleanup. The net environmental benefit of cleanup does not include environmental improvement resulting from natural recovery, as this improvement would occur in the absence of cleanup. The net environmental benefit also does not include consideration of monetary costs incurred during cleanup, as these costs are considered separately below.

Important benefits and impacts to human health and the environment are identified in Table 8-1. The benefits of cleanup include improvements in the health of the surrounding environment and in the health of humans

TABLE 8-1. COMPONENTS OF NET ENVIRONMENTAL BENEFITS, COST, AND TECHNICAL FEASIBILITY

NET ENVIRONMENTAL BENEFITS

Positive Benefits of Cleanup	Negative Impacts of Cleanup
Reduction of acute or chronic toxic effects to humans or the environment	Destruction or disturbance of benthic and aquatic communities and/or habitats
Reduction of cancers and genetic defects in humans or the environment	Short-term water quality impacts
Improvement in water quality	Increase in traffic and noise during cleanup at the site
Restoration of fisheries or shellfisheries, either by increases in numbers or by lifting fishing restrictions	Interference with shipping and/or recreational boating areas
Increase in population and diversity of species	Impacts to the environment at disposal sites
Improvement in recreational value	Traffic and human health impacts from transportation of wastes
Lifting of site use restrictions for future land use	
Improvement in aesthetic qualities	
Spiritual and cultural value	

COST

Planning
Capital
Materials
Labor
Operation and maintenance, including monitoring

TECHNICAL FEASIBILITY

Ability to reduce volume, toxicity, or mobility of contaminants
Short-term effectiveness
Long-term effectiveness
Reliability
Availability of materials and disposal sites
Permit requirements

that come into contact with sediments or consume food from areas near the site. Other benefits include improvement in water quality, improvement in the recreational and commercial value of the area, aesthetic improvements, and enhancement of cultural or spiritual values associated with a clean environment. The impacts of cleanup may include long-term or short-term destruction or disturbance of the environment surrounding the site and short-term impacts related to cleanup at the site, including increases in noise, traffic, injuries, and obstruction of navigation lanes or fishing areas. Impacts of cleanup may also include impacts to the environment at disposal sites and impacts during transportation of wastes to disposal sites.

Environmental benefits can be measured in various ways. For example, environmental health benefits can be measured in terms of diversity of species or productivity. Human health benefits can be measured in terms of a decrease in expected fatalities, cancers, toxic effects, injuries, or genetic defects. Recreational value can be measured by counting visits to an area for recreational purposes or by determining the increase in the number, types, or health of recreationally caught or collected species. Commercial values can be expressed in terms of dollars. Many of these benefits can be measured using more than one method. For example, recreational value can be measured (among other methods) by the number of people visiting an area, the number of fish caught, the market value of the fish caught, or the amount of money people spend to visit an area.

Because the net environmental benefits of cleaning up a site may not be known or predicted with certainty, simpler methods of estimating the environmental benefits associated with varying degrees of cleanup may be used. For example, the simplest measure might be the variation in the area of sediment cleaned up over the range of possible cleanup standards. A more complex approach might be to assign a value to different types of habitats within the site or site unit and assign values to the areas cleaned up accordingly. For example, cleaning up one square yard of intertidal rocky habitat might be assigned a greater environmental benefit value than cleaning up one square yard of soft-bottom silty sediment. For large or complex sites, a risk assessment and/or economic analysis may be used to determine more specifically the expected net environmental benefits of cleaning up a site.

In developing site-specific cleanup standards, it is important to note that the net environmental benefit may not always increase as cleanup standards become more stringent. Figure 8-4 shows an example of a site where an intermediate standard would provide the greatest net environmental benefit. The river mouth at this hypothetical site provides

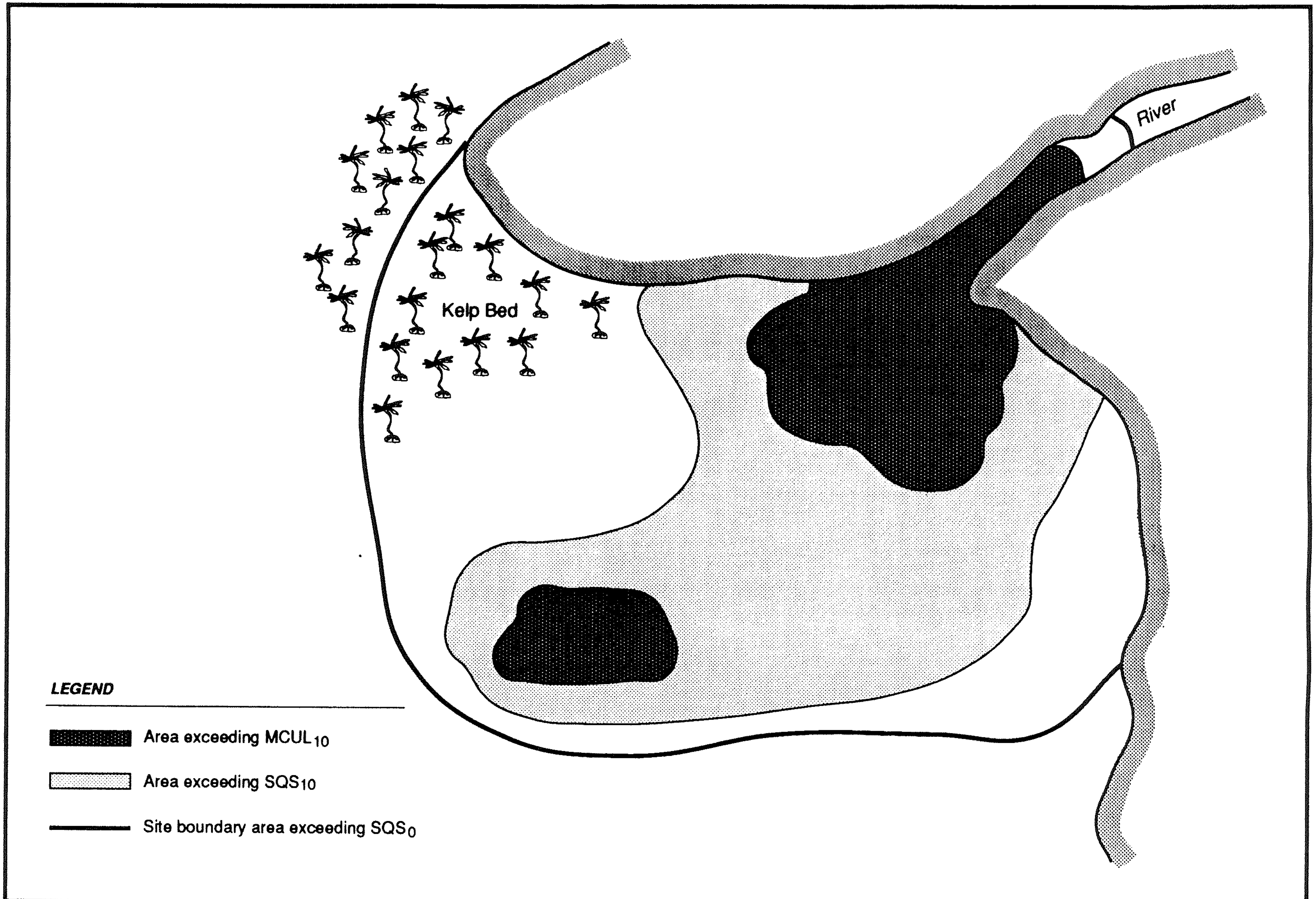

Figure 8-4. Example of net environmental benefit analysis.

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habitat for juvenile salmonid prey. This area also corresponds to the area of highest sediment contamination within the site. Because the benthic environment would be recolonized within a relatively short time after cleanup (i.e., 1-2 years), cleanup of this area would provide substantial environmental benefit. Cleanup of the area exceeding SQS_{10} would also provide environmental benefit by improving the overall sediment and water quality at the site, without disturbing sensitive habitats. However, cleanup of the entire site, corresponding to all areas that exceed SQS_0, would require destruction of a thriving kelp bed (which would not be expected to recolonize quickly). In the hypothetical scenario, contamination in this area is relatively low-level and would be expected to recover naturally within 5 years without disturbing the kelp bed. Under this scenario, selection of a site-specific cleanup standard near the SQS_{10} would provide the greatest environmental benefit.

Cost

Costs are defined as monetary expenditures associated with cleanup of a site. Types of costs that may be involved are listed in Table 8-1. These include the costs of planning (e.g., for cleanup studies, cleanup reports, and cleanup action plans), the capital, the materials, and the labor required to perform the cleanup, and the costs of monitoring and maintaining the containment structures for wastes remaining onsite. Compared to net environmental benefits, the costs of cleanup are relatively easy to identify and estimate. However, the comparison between costs and environmental benefits is not straightforward, primarily because many environmental benefits are not easily expressed in dollars.

At the stage of the cleanup study at which cleanup standards are chosen, the cleanup action to be used at the site will not have been developed sufficiently to allow a detailed, site-specific estimate of cleanup costs. To allow a preliminary comparison of costs to environmental benefits, costs will likely be developed in a generic fashion for general types of response actions. Ecology plans to develop costs associated with general cleanup actions, such as capping, dredging, and major disposal options, that would be applied at all sites in Puget Sound for development of cleanup standards. The cost of cleanup to a given standard would be equivalent to the cost of the general response option multiplied by the number of square yards (or cubic yards) that exceed that standard. The availability of these "unit costs" will streamline the process of selecting cleanup standards and will introduce uniformity among cleanup sites.

To develop a site-specific cleanup standard, the net environmental benefits of cleaning up a site must be compared with the costs of cleanup to determine an optimal level of cleanup. This comparison may be made subjectively, using different units of measurement for environmental benefits and costs, or the comparison may be performed quantitatively, by translating environmental benefits into dollars and comparing them directly to the costs of cleanup. Various methods of comparison are described in Section 8.3.3.

Technical Feasibility

Technical feasibility is defined as the ability of a cleanup alternative to be implemented at a site. Components of technical feasibility are listed in Table 8-2 and include the alternative's ability to reduce volume, toxicity, or mobility of contaminants; the alternative's long- and short-term effectiveness; and the reliability of the technologies involved. Additional considerations include the availability of capping materials or disposal sites and permit requirements.

Technical feasibility is introduced into the weighing process for selecting site-specific cleanup standards through a preliminary screening of the general response options (e.g., capping, dredging and disposal, and *in situ* treatment) available for the site. The preliminary screening step is performed as part of the cleanup study and is described in Section 9.2.1. Based on the preliminary screening, one general response action is chosen on which to base selection of the cleanup standards. This general response action represents the agency's best judgment of the most likely general response action that will be chosen for that site unit. The general response option that is chosen for a site or site unit affects the net environmental benefits associated with cleanup. The general response option is also used as the basis for developing preliminary costs of cleanup, as discussed above.

8.3.3 Methods for Weighing Net Environmental Benefit, Cost, and Technical Feasibility

Methods for weighing net environmental benefit, cost, and technical feasibility are under development by Ecology's Sediment Management Unit. Methods that are being considered by Ecology are described in this section and will be developed in more detail in a future draft. The methods described below range from subjective and qualitative (narrative method) to highly complex economic analyses (total value approach). Each method focuses on a comparison of costs and net environmental benefits; as described above, technical feasibility is primarily brought into consideration during the evaluation of cleanup alternatives as a basis for developing preliminary costs and benefits. For additional information on these methods, contact the Sediment Management Unit.

Screening Level Analysis

An initial screening of cost and environmental benefits may be performed prior to a more complex weighing analysis to determine whether an appropriate cleanup standard can be easily identified. Figure 8-2 shows the four possible outcomes of this screening procedure:

- If there is neither a significant difference in costs nor a significant difference in benefits between cleanup to the SQS_0 and the $MCUL_{10}$, then the lowest cleanup standard, SQS_0, would be chosen. The SQS_0 would be chosen in this case because it is representative of the long-term sediment quality goal for Puget Sound.
- If there is a significant difference in benefits, but not a significant difference in costs, the SQS_0 would be chosen.
- If there is a significant difference in cost, but not a significant difference in benefits, the $MCUL_{10}$ would be chosen.
- If there is a significant difference both in cost and in benefits between the SQS_0 and the $MCUL_{10}$, then a more detailed analysis of the trade-offs between cost, net environmental benefits, and technical feasibility would be performed to determine an appropriate cleanup standard within this range. Methods for more detailed analyses are described in subsequent sections.

Identifying Significant Cost Differences—The method used to determine whether cost differences are significant is based on methods used in the economic impact statement for the Sediment Management Standards (Ecology 1990). This method considers both the increase in costs of cleanup from the $MCUL_{10}$ to the SQS_0 and the total cost of cleanup. Under this approach, the cost difference would be considered significant if any of the following is true:

- The cost of cleanup to the SQS_0 is significantly greater than the cost of cleanup to the $MCUL_{10}$. Significance is defined on a sliding scale depending on the size of the site. For large cleanups, even small percentage differences in cost could be significant in terms of absolute cost. The following guidelines may be used:

- Small cleanups (<$250,000). The cost difference is significant if the cost of cleanup to the SQS_0 is more than twice the cost of cleanup to the $MCUL_{10}$
- Medium cleanups ($250,000–$10,000,000). The cost difference is significant if the cost of cleanup to the SQS_0 is more than 1.5 times the cost of cleanup to the $MCUL_{10}$
- Large cleanups (>$10,000,000). The cost difference is significant if the cost of cleanup to the SQS_0 is more than 1.1 times the cost of cleanup to the $MCUL_{10}$

- For privately funded cleanups, the total cost of cleanup to the SQS_0 (annualized over 10 years) is more than one-half the total annual sales of the liable parties
- For MTCA-funded cleanups, the total cost of cleanup to the SQS_0 (annualized over 10 years) is more than the annual amount of the Toxics Cleanup Program Account
- For sites with a mix of public and private funding, the total cost of cleanup to the SQS_0 (annualized over 10 years) is more than one-half the total sales of the liable parties plus the annual amount of the Toxics Cleanup Program Account.

Identifying Significant Differences in Environmental Benefits—A complete analysis of net environmental benefits associated with cleanup is complex and includes consideration of reductions in risk to human health and the environment after cleanup, increases in risks during cleanup or at disposal sites, and the potential effects of natural recovery. Procedures for the analysis are described in the following section. For this screening-level analysis, environmental benefits are assumed to be roughly proportional to the number of square yards cleaned up under the SQS_0 and the $MCUL_{10}$. The number of square yards cleaned up under each alternative would be considered the environmental benefit score of that alternative.

Because site units are chosen in part on the basis of habitat types and aquatic biota present, it is anticipated that, for most site units, the biological resources and habitat value associated with each square yard will be similar. However, if a site or site unit contains widely differing habitats and biological resources in various portions of the sediments to be cleaned up, the site manager may wish to weight the sediments according to their biological value. For example, standard subtidal soft-bottom sediments might be assigned one value, while rocky intertidal habitats might be assigned a higher value. The environmental benefit score of cleaning up to a particular cleanup standard would be the sum of the habitat values of each square yard of sediment cleaned up under that standard.

The environmental benefit scores, assuming cleanup to the SQS_0 and to the $MCUL_{10}$, are compared to determine whether there is a significant difference between them. A significant difference is identified when the score under the $MCUL_{10}$ alternative is less than 80 percent of the score under the SQS_0 alternative.

Summary— Under these guidelines, a detailed analysis of net environmental benefit, cost, and technical feasibility must be performed if 1) there is a significant difference in environmental benefits over the range of possible cleanup standards and 2) there is a significant difference in costs over the range of possible cleanup standards or if cleanup at the site potentially exceeds the funding that is reasonably available for the site. Procedures for more detailed analyses are described in the following sections.

Narrative Method

The narrative method of comparing environmental benefits with costs makes use of an approach similar to that used to compare cleanup alternatives under CERCLA. A set of alternative cleanup standards would be identified for evaluation, ranging from the SQS_0 to the $MCUL_{10}$, and including a number of intermediate standards for evaluation, such as the SQS_{10} and the $MCUL_0$, or any other intermediate standards judged appropriate. The environmental benefits, impacts, and costs associated with cleanup (listed in Table 8-1) would be determined for each alternative cleanup standard and listed in a matrix form for easy comparison. Figure 8-5 shows an example of a matrix for comparing alternative cleanup standards, using the site shown in Figure 8-4 as an example.

The matrix provides an overall score for net environmental benefits and costs, along with a breakdown of important factors that went into deriving the score. In the example, the $MCUL_{10}$ receives a medium score for net environmental benefits, because a sensitive area is being cleaned up that will not take long to recolonize. The SQS_{10} receives a high score because a much larger area is being cleaned up without appreciable impacts to the environment. The SQS_0 drops back to a medium score for net environmental benefits because, although a large area is cleaned up, cleanup entails the destruction of a kelp bed that may not recover easily. The costs of cleanup under each alternative are also listed and scored relative to each other (rather than to an absolute cost scale). The costs of cleanup are based on capping the sediments in place.

	ALTERNATIVE STANDARDS		
	$MCUL_{10}$	SQS_{10}	SQS_0
Net Environmental Benefits Score	Medium	High	Medium
Square Yards Cleaned Up	16,000	40,000	68,000
Type of Habitat	River mouth (juvenile salmonid prey area) and subtidal hot spot ⇨	Additional subtidal and nearshore habitat ⇨	Additional subtidal and nearshore habitat and kelp beds
Potential Impacts	Short-term disturbance of river mouth habitat (1-2 years recolonization time) ⇨	Additional impacts minimal ⇨	Destruction of kelp beds (uncertain recolonization time)
Costs Score	Low	Medium	High
Planning	$50,000	$50,000	$50,000
Cleanup	$368,000	$920,000	$1,564,000
Monitoring (5 years)	$150,000	$150,000	$150,000

Figure 8-5. Matrix for comparing alternative cleanup standards.

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Although the costs of planning are similar for each alternative, the cost of cleanup increases with the area to be capped. In each case, the costs of monitoring are similar, because the entire area exceeding SQS_0 must be monitored.

The matrix, along with a narrative explanation of each factor, is used to determine the most appropriate cleanup standard. The narrative portion would describe each factor and how it varies across the alternatives, the importance of that factor in making the overall choice of a cleanup standard, and the cleanup standard that was chosen based on the narrative evaluation. In the example shown, the SQS_{10} would be a likely choice for a cleanup standard, because it provides the greatest net environmental benefits at a moderate cost for the general response action that was identified.

Nonparametric Analysis

Like the matrix approach, the qualitative benefits evaluation also balances the cost of a cleanup action with the action's net environmental benefits. However, this approach uses a comparison of dollar values representing costs with a numerical scale representing environmental benefits. Although this approach does not require rigorous data collection and analysis to describe environmental benefits in terms of dollars, it does require establishing, at a minimum, a nonparametric ranking of environmental benefits and environmental impacts.

For some cleanup alternatives, this approach would also require a qualitative ranking of trade-offs between environmental benefits and environmental impacts. For example, if a cleanup alternative involves dredging with upland disposal of contaminated sediment, the approach would require establishing qualitative comparisons between the environmental benefits of removing contaminated sediments and the environmental costs of upland disposal (e.g., costs of lost upland habitat or increased risk of contamination of upland environments).

This type of evaluation may be amenable to a matrix-type analysis, where different matrices could be established for evaluating potential cleanup standards depending on the relative magnitude of cleanup costs (e.g., cleanup costs less than \$250,000, cleanup costs between \$250,000 and \$10 million, and cleanup costs greater than \$10 million). Figure 8-6 illustrates possible outcomes of cost and net environmental benefits for several cleanup alternatives at a small cleanup site. Alternatives with relatively low cost and high environmental benefits (Quadrant IV) would be favored over other alternatives.

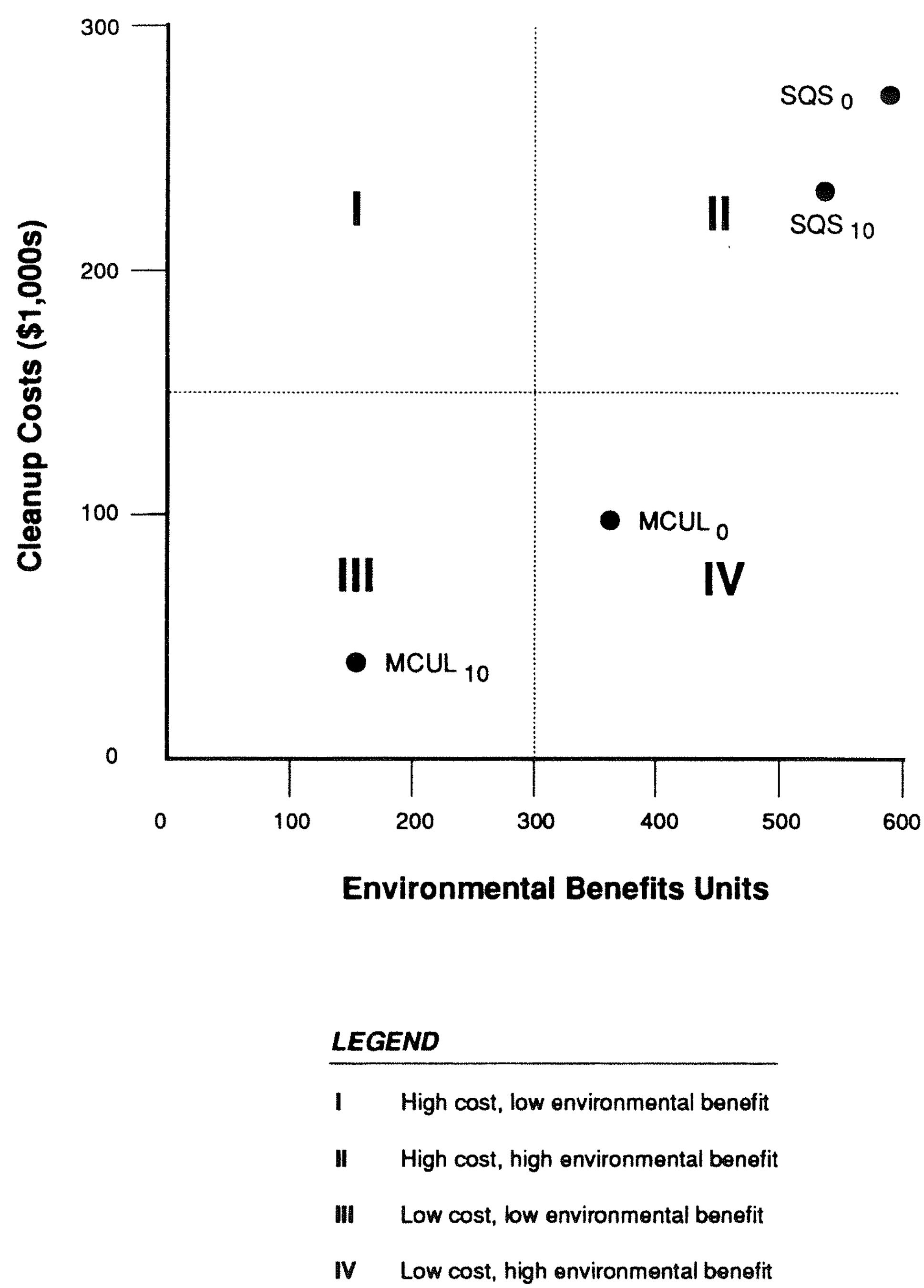

Figure 8-6. Example outcomes of nonparametric analysis of cleanup costs and environmental benefits.

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The most challenging task in implementing this approach is to establish a ranking or nonparametric valuation system for the wide range of environmental benefits that can be derived from site cleanup. These benefits will range from those that are purely ecological (e.g., greater species diversity or species abundance) to those that have direct human use implications (e.g., lifting of restrictions to recreational harvest of shellfish).

Total Value Method

The total value approach to setting a site-specific cleanup standard also balances the cost of a cleanup action with the net environmental effects of the cleanup action. Using this approach, the site-specific cleanup standard that maximizes the total value of the site's environment is identified. Both the costs and benefits of an action must be translated into dollars before this approach can be used. This requirement does not mean that only market effects (e.g., environmental impacts on commercial fisheries or tourism) are considered. It does mean, however, that the various environmental effects of a cleanup action must be assigned a dollar value. Once assigned, the dollar benefits of alternative cleanup standards can be compared to their dollar costs, and an optimal standard (the standard that maximizes total value) can be determined.

The total value approach is based on the assumption that the environment provides a variety of services to humans, the values of which can be expressed as dollar amounts. Some of these services include recreational opportunities, commercially exploitable natural resources, or opportunities for viewing natural sites. The value of these services can be measured by individuals' willingness to pay for them, even if there is no formal market for the services. For example, an individual who travels 60 miles to a favorite hiking spot "pays" for the hike by spending time and money traveling to the site. Appendix E describes these types of values in greater detail, along with the tools used by economists for estimating a wide range of values associated with natural resources.

The use of the total value approach to set site-specific cleanup standards requires three types of data:

- **Environmental Benefits**—The benefits resulting from the improvement of the environment caused by the cleanup action
- **Environmental Impacts**—The environmental impacts resulting from the degradation of the environment during or after cleanup

- **Direct Cleanup Costs**—The engineering and materials costs (and transportation and disposal costs, if offsite disposal is used) of the cleanup action.

For each site-specific standard under consideration, the environmental effects of the corresponding cleanup action must first be quantified, and then these effects must be assigned dollar values. In this way, the total value (net environmental benefits minus direct cleanup costs) can be calculated for any site-specific cleanup standard. The total value approach is most easily applied to a limited number of alternatives.

The next step is to maximize the net economic benefits of choosing a site-specific cleanup standard, where the net economic benefits equal the net environmental benefits minus the direct cleanup costs. The net economic benefits are calculated for each site-specific standard under consideration. This can be done by constructing a limited number of alternatives. Alternatively, mathematical functions may be constructed based on biological models of the relationship between sediment quality and environmental effects and economic studies of the dollar values of those effects. If the benefits and costs can be expressed as continuous functions of the cleanup standard, a more accurate selection of the optimal cleanup standard is possible.

The application of the total value approach is straightforward if the magnitudes of environmental effects associated with a cleanup action can be expressed in dollar values. The usefulness of this approach depends on the ease of quantifying the environmental effects of a cleanup action and assigning dollar amounts to these components, such as those in Table 8-1. In some cases, these values can be drawn from existing studies; in other cases, original (and expensive) studies must be performed before the total value approach can be used. Methods of assigning dollar amounts are discussed in greater detail in Appendix F.

9. SELECTION OF A CLEANUP ACTION

WAC 173-204-580

9.1 Cleanup Action Alternatives

As part of the cleanup study report, cleanup action alternatives are developed and evaluated for use at the site. This section describes the alternatives and technologies that are available for cleanup of contaminated sediments. Correction of contamination problems in and around Puget Sound will be accomplished through a combination of activities implemented under various authorities and by various parties. Cleanup actions involving dredging and disposal of sediments should be developed and performed in accordance with the Dredged Material Management Standards (currently in draft form).

9.1.1 Elements of a Complete Cleanup Action Alternative

Major elements of a cleanup action may include:

- Site use restrictions (e.g., public warnings and fisheries advisories to reduce potential human exposures)
- Source control measures to reduce or eliminate ongoing releases of substances and to prevent recontamination of sediments after cleanup, including:
  - Cleanup of upland facilities
  - Regulation of wastewater discharges
  - Implementation of stormwater and industrial pretreatment requirements
- Active cleanup action for contaminated site sediments that are expected to persist for unacceptable periods of time
- Natural recovery of areas of the site with relatively low levels of contamination through chemical degradation and deposition of clean sediments
- Maintenance and monitoring to characterize the effectiveness of source control, active cleanup, and natural recovery.

Cleanup action alternatives should address the interrelationship of these remedy elements, particularly with respect to timing. Site use restrictions should be in place before and during the cleanup, and should continue as long as contaminants are left onsite that could pose risks to human health. Source control should be timed appropriately to ensure that sediments are not recontaminated to unacceptable levels following active cleanup and so that natural recovery is possible. Sediment monitoring should continue as long as sediments remain contaminated above the SQS, and contingency plans should be included to provide corrective action if natural recovery or active cleanup does not meet the cleanup standards once the time of compliance has been reached.

9.1.2 Development of Cleanup Action Alternatives

Alternatives for sediment cleanup generally have three components: general response actions, cleanup technologies, and process options. "General response actions" refer to major categories of cleanup activities such as removal or treatment, "cleanup technologies" refer to general categories of technologies such as chemical treatment and thermal destruction, and "process options" refer to specific processes within each technology type (U.S. EPA 1988). For example, a general response action of treatment might include chemical, physical, biological, and thermal treatment. Chemical treatment technologies might include process options such as precipitation and ion exchange. General response actions and technologies that are available for cleanup of contaminated sediments are shown in Figure 9-1.

The identification of applicable remedial technologies and process options for each general response action should initially consist of a broad evaluation of the applicable remedial technologies that are available. Site-specific conditions greatly influence the number of cleanup technologies that will be effective at a particular site.

Process options and cleanup technologies may be eliminated from further consideration on the basis of technical implementability. This screening step relies on information obtained during the cleanup study and considers the following information:

- **Contaminant distributions**—The cooccurrence of inorganic and organic contaminants may limit applicable technologies
- **Contaminant concentrations**—Large volumes of low-level contamination are not as amenable to treatment as localized areas of high-level contamination

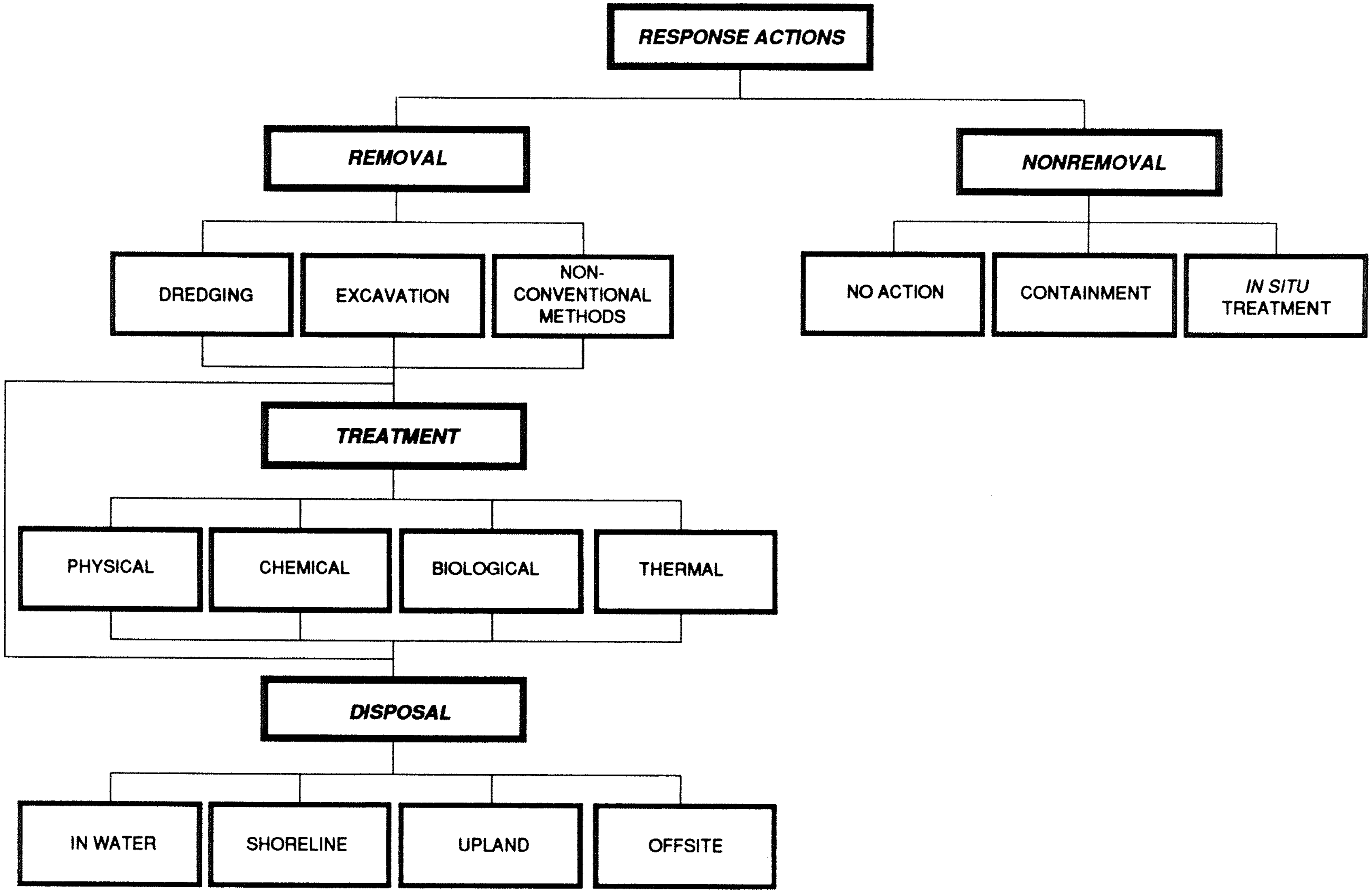

Figure 9-1. General response actions and technology types applicable to contaminated sediments.

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- **Site characteristics**—The physical location of contaminated sediments may limit the types of removal technologies considered
- **Sediment characteristics**—The physical characteristics of sediments may affect their ability to be dredged or capped.

Subsequent to this initial screening, process options may be further screened on the basis of the following criteria (U.S. EPA 1988):

- **Effectiveness**—Ability to handle estimated volumes and meet cleanup goals, ability to reduce potential human health and environmental impacts, and reliability
- **Implementability**—Technical and administrative feasibility, which at this stage is primarily institutional (i.e., ability to obtain permits for offsite actions and availability of treatment, storage, and disposal facilities)
- **Cost**—Differences among process options within particular technology types.

This screening step is intended to reduce the number of process options to be considered as part of each cleanup technology. Ideally, a single representative process, or combination of processes, would be identified for each cleanup technology for evaluation during the cleanup study.

In assembling alternatives, general response actions and the process options chosen to represent various technology types are combined to form alternatives for the site as a whole or for each site unit. Each cleanup alternative should include compatible cleanup technologies that are evaluated as a system to ensure that the overall response is protective of human health and the environment and that the technologies are complementary when implemented in combination.

One or more general response actions will probably be applied. Possible alternatives for remediating sediment depend on the type and the distribution of substances. For example, treatment may be considered for a site unit containing a small volume of sediments with high concentrations of contaminants, while confinement or natural recovery may be identified as the most likely candidate for site units with a large volume of sediments containing lower concentrations of contaminants.

As part of the development of cleanup action alternatives, technologies and process options should be defined in greater detail. The following information should be developed for the various process options used in an alternative:

- Size and configuration of onsite extraction and treatment systems or containment structures that would be needed
- Time frame in which treatment, containment, or removal can be achieved
- Spatial requirements for constructing treatment or containment technologies, or for staging construction material or excavated sediments
- Locations of available treatment or disposal facilities
- Required permits and action-specific ARARs.

Typical cleanup action alternatives for contaminated sediments are described in Appendix D.

9.2 Selection of a Cleanup Action

Selection of a cleanup action for the site or for each site unit is performed in three stages. During the cleanup study, a preliminary screening of the cleanup action alternatives is performed to aid in selecting cleanup standards for the site or site unit. Following the preliminary screening, the detailed analysis of alternatives is performed, and a preferred alternative is developed and identified in the cleanup study report. Subsequently, Ecology or EPA reviews the cleanup study report and may choose either one of the alternatives for cleanup action, none of the identified alternatives, or one of the alternatives with modifications (WAC 173-204-580). The public and affected landowners must be given an opportunity to comment on the draft cleanup study report and cleanup action decision.

9.2.1 Preliminary Screening of Cleanup Action Alternatives

Preliminary screening of cleanup action alternatives may be performed based on the long- and short-term aspects of three criteria: effectiveness, implementability, and cost. Only those alternatives passing these criteria need be retained for further consideration and detailed analysis. The no-action alternative should be retained throughout the evaluation process.

Once the preliminary screening has been performed, a general response action should be chosen to represent the remaining cleanup action alternatives for each site unit. This general response action is used in the development of cleanup standards for the site unit (described in Section 8.3.2), and represents Ecology's best professional judgment of the most likely general response action for that site unit.

9.2.2 Detailed Analysis and Selection of the Preferred Alternative

Alternatives retained from the preliminary screening phase should be further defined as necessary to allow a more accurate final evaluation. Factors such as process sizing can be refined based on the results of treatability studies. A more accurate definition of the quantities of sediment requiring capping, removal, treatment, and/or disposal should be calculated based on the results of the cleanup study.

The detailed analysis of alternatives consists of the presentation and analysis of the relevant information needed to allow decision-makers to select a site remedy. This detailed evaluation relies on data collected during the cleanup study and on the results of any treatability studies used to assess treatment technologies. During the detailed analysis, each alternative that passed preliminary screening is assessed relative to specific evaluation criteria. These criteria should include:

- Overall protection of human health and the environment by eliminating, reducing, or otherwise controlling risks posed through each exposure pathway and migration route.
- Compliance with cleanup standards and applicable laws, including time required to attain cleanup standards.
- Short-term effectiveness, including protection of human health and the environment during construction and implementation of the alternative.
- Long-term effectiveness, including degree of certainty that the alternative will be successful, long-term reliability, magnitude of residual human health and biological risks, effectiveness of controls for ongoing discharges, management of treatment residues, and disposal site risks.
- Ability to be implemented, including the potential for landowner cooperation, technical feasibility, availability of disposal facilities, services and materials required, administrative and regulatory requirements, schedule, monitoring requirements, access needs, operation and maintenance, and integration with existing facility operations and other current or potential cleanup actions.
- Cost, including consideration of present and future direct and indirect capital, operation and maintenance costs, and other foreseeable costs.
- The degree to which community concerns are addressed.
- The degree to which recycling, reuse, and waste minimization are employed.
- Environmental impacts, according to the requirements of Chapter 43.21C RCW, the SEPA. Discussion of significant short-term and long-term environmental impacts, significant irrevocable commitments of natural resources, significant alternatives including mitigation measures, and significant environmental impacts that cannot be mitigated should be included.

The cleanup action alternatives may include the establishment of a sediment recovery zone (SRZ) (discussed in more detail in Chapter 10) if active cleanup actions are not practicable. If a SRZ is part of a cleanup action alternative, the following additional criteria must be addressed as part of the cleanup study:

- The time period during which a SRZ is estimated to be needed, based on an analysis of source loading and environmental recovery processes
- The legal location and ownership of property proposed as a SRZ
- Operational terms and conditions that would be required, including chemical and/or biological monitoring requirements for the discharge effluent, the receiving water column, and sediments (see Chapter 11 for monitoring requirements)
- Potential risks posed by the proposed SRZ to human health and the environment
- The technical practicability of eliminating or reducing the size, degree of contamination, and/or degree of biological effects within the proposed SRZ
- Current and potential uses of the SRZ, surrounding areas, and associated resources that may be affected by releases within or from the proposed SRZ
- The need for institutional controls or site use restrictions to reduce risks to human health from the proposed SRZ.

The results of this assessment should be presented in a matrix to compare the alternatives and identify the key tradeoffs among them. This evaluation serves as the basis for selecting a preferred cleanup action alternative in the cleanup study report.

9.2.3 Agency Selection of a Cleanup Alternative

Based on the information presented in the cleanup study report, the lead agency has the option of selecting one of the alternatives described, an alternative with modifications or conditions, or none of the alternatives as appropriate for cleanup at the site. The agency's cleanup decision is based on the following criteria:

- The net environmental impacts of the alternatives, including 1) residual concentrations and their effects on human health and the environment, 2) natural recovery, and 3) environmental and human health impacts that may occur during implementation of the cleanup alternative because of construction of disposal or treatment facilities, capping, dredging, treatment, and transporting contaminated sediments

- The cleanup standards associated with each alternative and the relative cost-effectiveness of the alternatives in achieving the cleanup standards

- The technical effectiveness and reliability of each alternative.

These factors are considered during development of the cleanup standards for the site or site units and therefore should be documented in the cleanup study report. The report should include a discussion of the tradeoffs between these factors, to a level of detail sufficient to make a cleanup action decision.

The cleanup action decision must include the selection of a reasonable time frame within which the cleanup action must be completed. The following factors should be considered in selecting a time frame for compliance:

- Potential or actual risks posed by the site to human health or the environment

- Practicability of achieving the cleanup standards in less than a 10-year period

- Current uses of the site, surrounding areas, and associated resources that are or may be affected by contamination at the site

- Potential future uses of the site, surrounding areas, and associated resources that are or may be affected by contamination at the site

- Likely effectiveness and reliability of institutional controls

- Degree of contamination at the site

- Ability to control and monitor migration of contamination from the site

- Degree of source control and compliance time frame for planned source control actions

- Natural recovery processes that are expected to occur at the site (methods of predicting natural recovery are described in Appendix C).

Although a 10-year time frame is used in developing the cleanup standards for the site, Ecology may authorize natural recovery time frames that exceed 10 years if it is not practicable to accomplish cleanup actions within this amount of time.

10. SEDIMENT RECOVERY ZONES

WAC 173-204-590

SRZs are areas where sediments containing contaminants above the SQS are left in place as part of the cleanup action decision for a site or site unit. SRZs may be part of the cleanup action option in the following instances:

- When, because of the presence of widespread, low-level contamination, natural recovery is determined to be the preferred alternative for cleanup of a site or site unit
- When greater environmental harm would result through cleanup of the site than would result if the site were allowed to naturally recover (e.g., in areas with unique or sensitive resources or areas where resources would recolonize very slowly)
- When the cleanup standards for the site, chosen through consideration of cost, technical feasibility, and net environmental benefits, are higher than the SQSo
- When contaminated sediments are capped in place
- When cleanup of the site is not practicable.

In any of these situations, SRZs may be authorized for as large an area as is necessary. The goal of a SRZ is to achieve natural recovery to the SQS within 10 years, although SRZs may be authorized for longer time periods if cleanup of the site is not practicable. The time that will be required to achieve natural recovery to the SQS can be estimated using the methods presented in Appendix C. These methods range from literature reviews to relatively simple equations to the use of WASP4 (Ecology's sediment impact zone model) to predict natural recovery. WASP4 is the most flexible of these methods and is particularly recommended for modeling areas with ongoing sources and/or authorized sediment impact zones.

A SRZ must be specifically authorized by Ecology as part of the cleanup action decision and approval of the cleanup study report. In addition, the approval and cleanup action decision must contain a legal description of the property proposed as a SRZ, the landowners of the property, and the time period over which the SRZ is authorized. The site manager at Ecology must make a reasonable effort to notify the landowner(s) of the affected property and provide information on the SRZ application, as described in WAC 173-204-590(4). Landowners are given the opportunity to comment on the proposed SRZ within 30 days.

Biological and chemical monitoring of sediments, water, and/or effluent may be required as part of the SRZ authorization (see Chapter 11 for a discussion of monitoring) to ensure compliance with the terms and conditions of the authorization and to monitor the progress of natural recovery.

Should Ecology determine that the terms and conditions of the SRZ authorization have been violated, or have the potential to be violated, Ecology has four options:

- Require additional chemical or biological monitoring to better determine the potential for a violation
- Revise the terms of the SRZ authorization to reflect the needs of the site
- Require additional cleanup of the site or increased maintenance to prevent contaminants from migrating out of the SRZ
- Withdraw authorization of the SRZ.

These options may be applied singly or in combination to best achieve the goals of the Sediment Management Standards.

11. MONITORING

WAC 173-204-600

This section discusses the general types of monitoring that are conducted during the sediment cleanup decision process, how the monitoring objectives differ for the various types of monitoring, the different types of monitoring data that are applicable to the sediment cleanup decision process, and methods for the collection of monitoring data. Guidance on determining specific monitoring requirements for cleanup sites and for the interpretation of such monitoring data are under development by Ecology.

11.1 Types of Monitoring

There are three general types of monitoring that may be conducted in support of the sediment cleanup decision process:

- **Source control monitoring**—Source control monitoring is conducted prior to and following cleanup to determine how ongoing sources at or near the site may affect the success of active cleanup and natural recovery.

- **Compliance monitoring**—Compliance monitoring is conducted during the term of an authorized SRZ, with the intent to demonstrate that the site complies with all terms and conditions of the SRZ authorization.

- **Closure monitoring**—Closure monitoring is conducted following completion of active cleanup or closure of a SRZ to demonstrate successful cleanup of the sediment contamination. Closure monitoring must be performed before a site can be delisted.

In most cases, monitoring is the responsibility of the parties conducting cleanup. For cleanups conducted by Ecology, the site manager is responsible for ensuring that monitoring is conducted at the site.

11.2 Monitoring Objectives

The objectives of monitoring vary with the type of monitoring being conducted. The objectives for the three general types of monitoring are described below.

11.2.1 Source Control Monitoring

The primary objective of source control monitoring is to collect data necessary to determine whether ongoing sources at or near the site will interfere with achieving the site-specific cleanup standards during cleanup and/or natural recovery. Simple screening tools (requiring information on the nature of the wastewater to be discharged, based either on knowledge of the type of facility or on actual chemical analyses of the wastewater) or more complex models (requiring more detailed information on characteristics of the wastewater as well as on physical and chemical conditions in the receiving environment) may be used to predict equilibrium sediment conditions under specific discharge scenarios. These screening tools and models, and the data required for each, are described in detail in a companion guidance document, *Sediment Source Control Standards Guidance Document* (PTI 1991a), available from the Sediment Management Unit at Ecology.

11.2.2 Compliance Monitoring

The primary objective of compliance monitoring is to collect data necessary to demonstrate that all requirements of a SRZ authorization are being met. Such monitoring may include chemical and/or biological assessments of conditions within the SRZ to demonstrate that the maximum allowable contaminant concentrations and/or biological effects have not been exceeded within the SRZ and that natural recovery is proceeding at the expected pace.

11.2.3 Closure Monitoring

For closure monitoring following active cleanup, the objective is to demonstrate that the cleanup was successful at remediating the sediment contamination that existed within the site to the site-specific cleanup standards. For SRZ closure, the objective of closure monitoring is to verify that natural recovery has been successful in achieving the site-specific cleanup standards.

11.3 Types of Monitoring Data

There are several different types of monitoring data that are used to meet the above objectives:

- Chemical data for site sediments
- Biological data for site sediments
- Physical data pertaining to the site
- Chemical data for sources
- Physical data for sources.

Some types of monitoring data may be important for only one aspect of the sediment cleanup decision process (e.g., physical monitoring of the site may be necessary if the WASP4 model is chosen to model the SRZ, but may not be necessary after the SRZ is authorized). Other types of monitoring data may be important in all aspects of the sediment cleanup decision process (e.g., chemical or biological monitoring data). The various types of monitoring data and the potential uses of the data are described in greater detail below.

11.3.1 Chemical Data for Site Sediments

Sediment chemistry data are most important during compliance and closure monitoring. The contaminant concentrations within an authorized SRZ must be monitored to determine whether the terms and conditions of the SRZ authorization are being complied with. Contaminant concentrations in the sediments following active cleanup or closure of a SRZ will be monitored to evaluate whether the site-specific cleanup standards have been met. In certain circumstances, it may be appropriate to collect data on subsurface as well as surface sediment quality conditions. For example, contaminant concentrations in subsurface sediments may be important in establishing sedimentation rates used in predicting the effects of natural recovery.

11.3.2 Biological Data for Site Sediments

Biological monitoring data, consisting of information on the abundances of naturally occurring benthic infaunal organisms and the results of sediment bioassays, are used primarily as a method of confirming the results of sediment chemistry data. Sediments that either achieve or fail the site-specific cleanup standards based on chemical concentrations may be evaluated using biological effects data for compliance with the narrative standards that the chemical standards represent. The results of these biological tests may override the results of the sediment chemistry analyses. Alternatively, both biological and chemical cleanup standards or SRZ conditions may need to be met.

11.3.3 Physical Data Pertaining to the Site

Data on physical conditions in the site environment are collected primarily to support models used to predict natural recovery, such as WASP4. The types of physical data that may need to be collected include vertical profiles of the density of the receiving water (generally calculated from the temperature and salinity of the receiving water), ambient current velocities, particulate concentrations in the water column, ambient sedimentation rates, and physical characteristics of the sediments (e.g., sediment grain size). WASP4 can be run with varying degrees of site-specific data. In some cases, default values for many of the model input parameters can be used, while in other cases, detailed site-specific data are required to run the models. Guidance on the appropriate data requirements for various types of model runs is provided in *Sediment Source Control Standards Guidance Document* (PTI 1991a), available from the Sediment Management Unit at Ecology.

11.3.4 Chemical Data for Sources

Data on the chemical characteristics of sources may be used to predict the effect of ongoing sources on the success of cleanup and natural recovery. Data on the concentrations of chemical contaminants in the wastewater may be used in simple screening tools to determine whether the discharge is likely to result in sediment contamination sufficient to exceed cleanup standards or the terms of a SRZ authorization. The data required for such a use include the concentrations of any of the contaminants in the discharge for which there are site-specific cleanup standards, as well as the concentration of particulates in the wastewater. Such data may also be used as input to WASP4 in more detailed analyses. Data on the concentrations of chemical contaminants in the discharge may also be used to verify that the discharge is achieving AKART or some other level of source control required as part of site cleanup.

11.3.5 Physical Data for Sources

The collection of physical data on the wastewater discharge will likely be necessary if WASP4 is used to predict the effects of natural recovery or the success of active cleanup. The types of physical data likely to be needed include the flow of the discharge (to estimate total loading to the receiving water), the density of the wastewater (generally calculated from the temperature of the wastewater), and the concentration of particulates in the wastewater. As indicated above, WASP4 can be run with varying degrees of site-specific data. In some cases, default values for many of the model input variables can be used, while in other cases, detailed site-specific data are required to run the model. Guidance on the appropriate data requirements for various types of model runs is provided in the *Sediment Source Control Standards Guidance Document* (PTI 1991a), available from the Sediment Management Unit at Ecology.

11.4 Methods for Collecting Monitoring Data

This section briefly describes the methods appropriate for the collection of various types of monitoring data. In cases where the methods have been described in other documents, appropriate references to those documents are provided. For methods that are not well documented, additional details are provided.

11.4.1 Chemical Monitoring of the Site

Data on chemicals in the receiving environment to be collected for evaluating sediment quality for compliance and closure monitoring include both conventional sediment variables and sediment contaminant concentrations. Methods for collecting these data are described briefly in the following sections.

Conventional Sediment Variables

Measurement of conventional sediment variables is valuable to help interpret the concentrations of sediment contaminants. TOC, for instance, should normally be measured whenever the concentrations of nonionic organic compounds are to be measured, because the numerical SQS and CSL criteria (and therefore, the site-specific cleanup standards) for those compounds are TOC-normalized. Acid volatile sulfides (AVS) should be measured whenever the concentrations of metals are to be measured, because AVS data are useful for interpreting the toxicity of metals in sediments. Analysis of ammonia is also potentially useful for interpreting bioassay results. Guidelines for the collection of sediment samples and for the analyses of conventional sediment variables are provided in PSEP (1986b).

Sediment Contaminant Concentrations

To determine whether sediment samples contain any contaminants at concentrations above the site-specific cleanup standards or to use information on the concentrations of sediment contaminants as input to WASP4, the sediments should be analyzed for all contaminants for which there are site-specific cleanup standards. If there are other contaminants known or suspected to be at the site that are likely to be toxic but for which there are presently no criteria [i.e., "other toxic, radioactive, biological, or deleterious substances," see WAC 173-204-320(5)], these contaminants should also be analyzed for, because their presence in the sediments may necessitate the assessment of the concentration below which they would have no adverse effects, by methods to be determined by Ecology.

Guidelines on the collection of sediment samples are provided in PSEP (1986b). Metals should be analyzed according to the guidelines provided in PSEP (1989b), and organic compounds should be analyzed according to the guidelines provided in PSEP (1989a). It is important that subsamples of sediment samples analyzed for nonionic organic compounds be analyzed for TOC as well in order to normalize the resulting concentrations by their TOC contents. It is also important that the analytical laboratory be instructed to employ all necessary methods to attempt to achieve the target detection limits specified in the PSEP protocols (PSEP 1989a,b).

11.4.2 Biological Monitoring of the Site

Biological testing to assess compliance with site-specific cleanup standards or a SRZ authorization may include the conduct of sediment bioassays or the assessment of the naturally occurring community of benthic infauna in sediment samples. Methods for the conduct of such biological tests are described briefly in the following sections.

Sediment Bioassays

Four of the biological tests that can be applied to assessments of sediment quality under the Sediment Management Standards are sediment bioassays, including:

- **Amphipod**—A 10-day acute sediment bioassay which assesses mortality of the amphipod *Rhepoxynius abronius*
- **Larval**—Any one of several acute sediment bioassays which assess mortality or abnormality of larvae of the following organisms:
  - Pacific oyster, *Crassostrea gigas*
  - Blue mussel, *Mytilus edulis*
  - Purple sea urchin, *Strongylocentrotus purpuratus*
  - Sand dollar, *Dendraster excentricus*
- **Juvenile polychaete**—A 20-day chronic sediment bioassay that assesses decreases in growth of the juvenile polychaete *Neanthes arenaceodentata*

- **Microtox® saline extract**–A 15-minute bioassay that assesses decreased bioluminescence of the bacteria *Photobacterium phosphoreum* exposed to a saline extract of the sediment sample. Although conducted for a relatively short period of time, the Microtox® bioassay is considered to be a chronic test.

Guidelines for the collection of sediment samples and for the conduct of these bioassays are provided in PSEP (1991a).

Assessment of Benthic Infauna

The fifth biological test that can be applied to determine sediment quality is assessment of the naturally occurring community of benthic infauna in samples of the sediment of interest. This test assesses statistically significant alterations in the abundances of the following major taxa: Crustacea, Mollusca, and Polychaeta. Guidelines for the collection and analysis of benthic infaunal samples are provided in PSEP (1987).

11.4.3 Physical Monitoring of the Site

Data on physical conditions in the receiving environment to be collected to support the use of WASP4 may include vertical density profiles, ambient current velocities, ambient particulate concentrations, sedimentation rates, and sediment grain size. Methods for the collection of such data are described briefly in the following sections.

Vertical Density Profiles

Vertical density profiles, which may be necessary for detailed discharge modeling, are typically generated from temperature and salinity data. Temperature and salinity (or conductivity) are generally measured electronically with submersible probes (e.g., conductivity-temperature-depth devices) lowered from a boat. Less frequently, temperature may be measured using reversing thermometers, and salinity may be determined by returning the samples to the laboratory for measurement with a salinometer. Recommended procedures for measuring temperature and salinity are described in PSEP (1991b). Measurements should be made over the entire water column at the site of the discharge and at sufficient intervals to provide representative data for periods of maximum and minimum stratification.

Ambient Current Velocities

Ambient current velocities are typically measured with current meters. Multiple current meters are usually arrayed along a taut-line mooring, which is deployed in the immediate vicinity of an outfall. Records of currents are typically made over periods of several weeks; the period of monitoring should take into account the possible effects of variations in both tidal influences and nontidal influences (e.g., wind-induced currents).

Ambient Particulate Concentration

Determination of ambient particulate concentrations normally entails collection of water samples from the water column and analysis for total suspended solids (TSS). Sample collection and analytical procedures are described in PSEP (1991b). If data on ambient particulate concentrations are required, the sampling strategy should address temporal and spatial variability of this variable, which is likely to be high.

Sedimentation Rates

The usual method of estimating sedimentation rates is through the use of sediment traps, which are cylinders, closed at the bottom, that are placed vertically in the water column to collect settling particles [see U.S. GOFS (1989), Norton (1990) for description of sediment trap design and use]. Because sediment traps are left in place for a period of time (from 2 weeks to a month), sediment traps are useful for characterizing average loadings of particles from an intermittent or variable source, such as a storm drain. The advantages of sediment traps are that they are inexpensive and easy to maintain. The primary disadvantage is that the particles collected are from all sources, both natural and anthropogenic, and not just from the discharge of interest.

Sediment traps should be used in areas that do not receive heavy boat traffic. The traps should be placed close to the source, far enough above the bottom that sediment resuspension will not substantially dilute the particles from the source that are found in the trap. Traps are typically poisoned with mercuric chloride or salt to minimize biotransformation of organic chemicals. However, a poison should be selected that does not interfere with the analytes of interest. To minimize preservation concerns, valves that prevent entry of zooplankton into the traps have been incorporated into recent sediment trap designs.

Sediment Grain Size

Determination of sediment grain size may be important in modeling of sediment resuspension. Sample collection and analysis procedures are described in PSEP (1986b). The sampling strategy should take into account spatial differences in sediment grain size, as well as temporal differences that may occur, especially in areas with seasonal differences in flow regime.

11.4.4 Chemical Monitoring of Sources

Data on the chemical characteristics of sources to be used in simple screening procedures, such as input to WASP4, or to verify achievement of specific source control measures may include both contaminant concentrations in whole wastewater samples as well as contaminant concentrations in wastewater particulates. Methods for the collection of these data are described briefly in the following sections.

Contaminant Concentrations in Whole Wastewater Samples

Contaminant concentrations in whole wastewater samples may be used to estimate contaminant loading to the receiving environment. Routine analyses of EPA priority pollutant metals and organic compounds are included as monitoring requirements for many permitted discharges, regardless of whether they are associated with a cleanup site. Wastewater samples may be collected either as grabs or as flow-weighted composites; the latter are generally preferred because they integrate over short time scales (e.g., 24 hours). If there is likely to be substantial variability in wastewater quality on longer time scales (e.g., due to seasonal variations in stormwater runoff), it may be desirable to sample at various time intervals to gain an understanding of the range of wastewater quality.

Contaminant Concentrations in Wastewater Particulates

If data are needed on the contaminant concentrations associated with wastewater particulates, sufficient solid sample must be collected to analyze for the contaminants of interest, and this may represent a technical challenge if the concentration of suspended particulates is relatively low. One method for obtaining a sample of particulates from a wastewater sample is to pass the water through a high-speed, continuous centrifuge. This method retains nearly all the particulates present in the water. The centrifuge can be located at the facility, or a water sample can be taken at the site and centrifuged in a laboratory. The latter method may require a large volume of water to be transported, however, if the concentration of suspended particulates is low. Because this procedure involves collection of a particulate sample at a single point in time, it is best used to characterize sources that are continuous and relatively stable. Alternatively, a periodic monitoring program may be employed.

A less costly method of obtaining a particulate sample from wastewater is filtration. However, compared to the centrifuge method, filtration is time-consuming and may not be appropriate for use when a large water sample is needed to collect the required amount of solids for analysis. A discussion of the relative merits of the centrifuge and filtration methods can be found in Horowitz (1986). Methods for analysis of particulate samples are discussed in Tetra Tech (1986). Ecology (1991) provides details on collection and analysis of particulate samples using a centrifuge.

11.4.5 Physical Monitoring of Sources

Physical data on sources to support application of WASP4 may include the concentration of particulates in the wastewater and discharge flow. Methods for collecting these data are described briefly in the following sections.

Concentration of Particulates in the Wastewater

The concentration of particulates in the wastewater may be needed for the use of simple screening tools and as input to WASP4. It is typically reported as the TSS content. The collection of samples for analysis of TSS should reflect knowledge of discharge conditions that are likely to result in temporal variability of the TSS content of the wastewater. Multiple samples are recommended to gain some idea of the variability of TSS content, which for some types of discharges may be extremely high. The analysis of TSS is conducted by filtering a sample of the wastewater, drying the filter, and weighing the filter by standard methods (APHA 1989).

Discharge Flow

Information on the flow of the discharge is needed to estimate contaminant loading to the site and as input to WASP4. Flow is typically monitored and reported for most permitted wastewater discharges, regardless of whether they are associated with a site. Flow can be measured *in situ* using a variety of methods. There are two major categories of methods for measuring flow: direct-discharge and velocity-discharge (Metcalf & Eddy 1979). The direct-discharge methods are used most frequently, and relate the rate of discharge to one or two easily measured variables, employing devices such as weirs, Parshall flumes, Venturi meters, and magnetic flow meters. Flow should normally be measured downstream of all treatment processes. The most useful flow measurements are those made continuously and recorded automatically because they provide a temporal record of flow variations.

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13. GLOSSARY OF TERMS

[Note: Please review this list of terms and add or delete any as appropriate. We will provide definitions in the next draft, after receiving your comments.]

abnormality

adverse biological effect

amphipod bioassay

ARAR

best management practice

best professional judgment

bioaccumulation

bioconcentration

biological effect

biological resource

capping

CERCLA

chlorinated organic compound

chronic test

cleanup level

cleanup objective

cleanup screening level

cleanup site

cleanup standard

cleanup technology

confined aquatic disposal

confirmational monitoring

contiguous

deposition rate

dredging

ecological hazard

effluent

general response action

GIS

hazard assessment

human health hazard

in situ

juvenile polychaete

landowner

larval

larval bioassay

LD_{50}

LD_{LO}

lessee

LOAEL

MCUL

Microtox

minimum cleanup level

Model Toxics Control Act

monitoring

natural recovery

NOAEL

nonparametric

octanol-water partitioning coefficient (K_{OW})

open-water disposal

PLP

process option

QA/QC

quality control

quality assurance

ranking

RfD

screening

sediment

sediment impact zone

Sediment Management Standard

Sediment Quality Standard

sediment recovery zone

Sediment Source Control Standard

sedimentation rate

SEDQUAL

SEDRANK

sensitive environment

sensitive resources

similarity index

site listing

station cluster

station clusters of low concern

station clusters of potential concern

SURFER

Thiessen polygon

total organic carbon

toxicity (or toxicity)

variance

WARM

Water Pollution Control Act

14. SUBJECT INDEX

[To be provided by Ecology]

APPENDIX A

Worksheets

WORKSHEET 1
Station Cluster Screening Using Chemical Data

Station Cluster ID: ______________________
(see reverse side for list of stations)

Contaminant	3 Highest Concentrations			Average of 3 Highest Concentrations	Average Exceeds CSL?	
	1	2	3		Yes	No
1.					☐	☐
2.					☐	☐
3.					☐	☐
4.					☐	☐
5.					☐	☐
6.					☐	☐
7.					☐	☐
8.					☐	☐
9.					☐	☐
10.					☐	☐
11.					☐	☐
12.					☐	☐
13.					☐	☐
14.					☐	☐
15.					☐	☐
16.					☐	☐
17.					☐	☐
18.					☐	☐
19.					☐	☐
20.					☐	☐

Station Cluster Designation:

☐ Station cluster of low concern (no averages exceed CSL)

☐ Station cluster of potential concern (at least one average exceeds CSL)

Name: ______________________ Date: ______________________

List the stations that are included in the station cluster:

1. ______
2. ______
3. ______
4. ______
5. ______
6. ______
7. ______
8. ______
9. ______
10. ______
11. ______
12. ______
13. ______
14. ______
15. ______
16. ______
17. ______
18. ______
19. ______
20. ______
21. ______
22. ______
23. ______
24. ______
25. ______

WORKSHEET 2
Station Cluster Screening Using Biological Data

Station Cluster ID: ______________

(see reverse side for list of stations)

	Amphipod Bioassay	Larval Bioassay	Chronic Test	Total Tests Failed	Fail *	Pass
Station # ______	Fails SQS ☐ Fails CSL ☐	Fails SQS ☐ Fails CSL ☐	Fails SQS ☐ Fails CSL ☐	Fails SQS ☐ Fails CSL ☐	☐	☐
Station # ______	Fails SQS ☐ Fails CSL ☐	Fails SQS ☐ Fails CSL ☐	Fails SQS ☐ Fails CSL ☐	Fails SQS ☐ Fails CSL ☐	☐	☐
Station # ______	Fails SQS ☐ Fails CSL ☐	Fails SQS ☐ Fails CSL ☐	Fails SQS ☐ Fails CSL ☐	Fails SQS ☐ Fails CSL ☐	☐	☐

* A station fails if 2 or more tests fail SQS or if one or more tests fail CSL; see Table B-2.

Station Cluster Designation:

☐ Station cluster of low concern (0-2 stations fail)

☐ Station cluster of potential concern (all 3 stations fail)

Name: ______________ Date: ______________

List the stations that are included in the station cluster:

1. ____________________
2. ____________________
3. ____________________
4. ____________________
5. ____________________
6. ____________________
7. ____________________
8. ____________________
9. ____________________
10. ____________________
11. ____________________
12. ____________________
13. ____________________
14. ____________________
15. ____________________
16. ____________________
17. ____________________
18. ____________________
19. ____________________
20. ____________________
21. ____________________
22. ____________________
23. ____________________
24. ____________________
25. ____________________

WORKSHEET 3
Site Identification Using Biological Data

Station Cluster ID: ______________________
(see reverse side for list of stations)

	Amphipod Bioassay	Larval Bioassay	Chronic Test	Total Tests Failed	Fail *	Pass
Station # ________	Fails SQS ☐ Fails CSL ☐	Fails SQS ☐ Fails CSL ☐	Fails SQS ☐ Fails CSL ☐	Fails SQS ☐ Fails CSL ☐	☐	☐
Station # ________	Fails SQS ☐ Fails CSL ☐	Fails SQS ☐ Fails CSL ☐	Fails SQS ☐ Fails CSL ☐	Fails SQS ☐ Fails CSL ☐	☐	☐
Station # ________	Fails SQS ☐ Fails CSL ☐	Fails SQS ☐ Fails CSL ☐	Fails SQS ☐ Fails CSL ☐	Fails SQS ☐ Fails CSL ☐	☐	☐

* A station fails if 2 or more tests fail SQS or if one or more tests fail CSL; see Table B-2.

Site Designation:
- ☐ Station cluster of low concern (0-2 stations fail) - attach completed Worksheet 4
- ☐ Site (all 3 stations fail)

Name: ______________________ Date: ______________

List the stations that are included in the station cluster:

1. __________
2. __________
3. __________
4. __________
5. __________
6. __________
7. __________
8. __________
9. __________
10. __________
11. __________
12. __________
13. __________
14. __________
15. __________
16. __________
17. __________
18. __________
19. __________
20. __________
21. __________
22. __________
23. __________
24. __________
25. __________

WORKSHEET 4
Site Identification Using Chemical Data

Station Cluster ID: ______________________
(see reverse side for list of stations)

Contaminant	**3 Highest Concentrations** (at stations where biological CSLs are not met)			**Average of 3 Highest Concentrations**	**Average Exceeds CSL?**	
	1	2	3		Yes	No
1.					❑	❑
2.					❑	❑
3.					❑	❑
4.					❑	❑
5.					❑	❑
6.					❑	❑
7.					❑	❑
8.					❑	❑
9.					❑	❑
10.					❑	❑
11.					❑	❑
12.					❑	❑
13.					❑	❑
14.					❑	❑
15.					❑	❑
16.					❑	❑
17.					❑	❑
18.					❑	❑
19.					❑	❑
20.					❑	❑

Site Designation:
❑ Station cluster of low concern (no averages exceed CSL)
❑ Site (at least one average exceeds CSL)

Name: ______________________ Date: ______________________

List the stations that are included in the station cluster:

1. __________
2. __________
3. __________
4. __________
5. __________
6. __________
7. __________
8. __________
9. __________
10. __________
11. __________
12. __________
13. __________
14. __________
15. __________
16. __________
17. __________
18. __________
19. __________
20. __________
21. __________
22. __________
23. __________
24. __________
25. __________

APPENDIX B

Reference Tables

TABLE B-1. MARINE SEDIMENT QUALITY STANDARDS AND CLEANUP SCREENING LEVELS FOR PUGET SOUND

Chemical Parameter	SQS[a]	CSL and MCUL[a]
Metals (mg/kg dry weight)		
Arsenic	57	93
Cadmium	5.1	6.7
Chromium	260	270
Copper	390	390
Lead	450	530
Mercury	0.41	0.59
Silver	6.1	6.1
Zinc	410	960
Nonionizable Organic Chemicals (mg/kg organic carbon)		
LPAH[b]	370	780
Naphthalene	99	170
Acenaphthalene	66	66
Acenaphthene	16	57
Fluorene	23	79
Phenanthrene	100	480
Anthracene	220	1,200
2-Methylnaphthalene	38	64
HPAH[c]	960	5,300
Fluoranthene	160	1,200
Pyrene	1,000	1,400
Benz(a)anthracene	110	270
Chrysene	110	460
Total benzofluoranthenes[d]	230	450
Benzo(a)pyrene	99	210
Indeno(1,2,3-c,d)pyrene	34	88
Dibenz(a,h)anthracene	12	33
Benzo(g,h,i)perylene	31	78
1,2-Dichlorobenzene	2.3	2.3
1,4-Dichlorobenzene	3.1	9
1,2,4-Trichlorobenzene	0.81	1.8
Hexachlorobenzene	0.38	2.3
Dimethyl phthalate	53	53
Diethyl phthalate	61	110

TABLE B-1. (Continued)

Chemical Parameter	SQS[a]	CSL and MCUL[a]
Di-n-butyl phthalate	220	1,700
Butylbenzyl phthalate	4.9	64
Bis(2-ethylhexyl) phthalate	47	78
Di-n-octyl phthalate	58	4,500
Dibenzofuran	15	58
Hexachlorobutadiene	3.9	6.2
N-nitrosodiphenylamine	11	11
Total PCBs	12	65
Ionizable Organic Chemicals (mg/kg dry weight)		
Phenol	0.42	1.2
2-Methylphenol	0.063	0.063
4-Methylphenol	0.67	0.67
2,4-Dimethylphenol	0.029	0.029
Pentachlorophenol	0.36	0.69
Benzyl alcohol	0.057	0.073
Benzoic acid	0.65	0.65

[a] SQS - sediment quality standards
CSL - cleanup screening levels
MCUL - minimum cleanup levels

When laboratory analysis indicates a chemical is not detected in a sediment sample, the detection limit shall be reported and must be at or below the criteria value shown in this table. Where chemical criteria in this table represent the sum of individual compounds or isomers, and a chemical analysis identifies an undetected value for one or more individual compounds or isomers, the detection limit shall be used for calculating the sum of the respective compounds or isomers.

[b] The LPAH criterion represents the sum of the following low molecular weight polycyclic aromatic hydrocarbons (PAHs): naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, and anthracene. The LPAH criterion is not the sum of the values for the listed individual LPAH compounds.

[c] The HPAH criterion represents the sum of the following high molecular weight PAHs: fluoranthene, pyrene, benz(a)anthracene, chrysene, total benzofluoranthenes, benzo(a)pyrene, indeno(1,2,3-c,d)pyrene, dibenz(a,h)anthracene, and benzo(g,h,i)perylene. The HPAH criterion is not the sum of the values for the listed individual HPAH compounds.

[d] The total benzofluoranthenes criterion represents the sum of the concentrations of the b, j, and k isomers.

TABLE B-2. BIOLOGICAL EFFECTS CRITERIA[a]

Biological Test	SQS[b]	CSL[c]
Amphipod	absolute mortality >25 percent and is higher than reference	mortality >30 percent + reference mortality
Larval	mortality and abnormality >15 percent + reference mortality and abnormality	mortality and abnormality >30 percent + reference mortality and abnormality
Benthic infauna	mean abundance of one major taxon[d] <50 percent of reference	mean abundance of two major taxa[d] <50 percent of reference
Juvenile polychaete	mean biomass <70 percent of reference	mean biomass <50 percent of reference
Microtox	mean light output <80 percent of reference	not applicable

[a] All observed differences between a test sample and the reference sample must be statistically significant, as measured by a *t*-test with $p \leq 0.05$.

[b] SQS - sediment quality standards.

[c] CSL - cleanup screening levels.

[d] Major taxa include Crustacea, Mollusca, and Polychaete.

TABLE B-3. PERFORMANCE STANDARDS FOR BIOLOGICAL TESTS[a]

Biological Test	Reference Area Sediments	Control Sediments or Seawater Control Sample[b]
Amphipod bioassay	<25% mortality	<10% mortality
Larval bioassay	Not applicable	<50% combined mortality and abnormality
Juvenile polychaete	Mean biomass at least 80% of the mean biomass for the control sediment	<10% mortality

[a] Quantitative performance standards for Microtox and benthic infaunal analysis are under development by Ecology. Qualitative performance standards for benthic infaunal analyses [as stated in WAC 173-204-315(2)(c)] are as follows: 1) the taxonomic richness of benthic macroinvertebrates and the abundances of higher taxonomic groups shall reflect seasonality and natural physical-chemical conditions (e.g., grain size composition and salinity of sediments, water depth) in a reference area, and not be obviously depressed as a result of chemical toxicity; 2) normally abundant species that are known to be sensitive to chemical contaminants shall be present; 3) normally rare species that are known to become abundant only under chemically disturbed conditions shall be rare or absent; and 4) the abundances of normally rare species that control community structure through physical modification of the sediment shall be similar to those observed at the test sediment size.

[b] Seawater control sample used for larval bioassay only.

APPENDIX C

Predicting the Effects of Natural Recovery

PREDICTING THE EFFECTS OF NATURAL RECOVERY

Several activities in the sediment cleanup decision process require predicting the effects of natural recovery. First, natural recovery may be a cleanup action alternative, either alone or in combination with active cleanup actions. Second, natural recovery predictions are used to estimate the upper end of the possible range of site-specific cleanup standards, $MCUL_{10}$. Third, an estimate of the time frame for natural recovery is important for authorization of a sediment recovery zone.

Natural recovery of contaminated sediments primarily occurs through three processes:

- Burial of contaminated sediments through natural deposition of clean sediments
- Mixing of cleaner surface sediments with contaminated deeper sediments by burrowing organisms, ship scour, prop wash, and natural water currents
- Loss of contaminants through biodegradation or diffusion into overlying water.

The rate of natural recovery will also be affected by the rate that contaminants are introduced into the environment by ongoing sources. If sources of contaminants to the site have been inactive for at least 5 years and historical sediment data are available for that time period, it may be possible to estimate natural recovery rates for the site empirically using data collected during the hazard assessment and chemistry data collected during the cleanup study.

If sources are ongoing or have recently ceased, or if historical sediment chemistry data are not available, a mathematical model may be used to estimate natural recovery in sediments. For example, the mathematical model (SEDCAM) described below was developed for the Commencement Bay feasibility study to estimate the natural recovery that will occur in contaminated sediments given specific conditions of source loading, sediment deposition, and chemical-specific loss factors (Jacobs et al. 1988). Alternatively, the sediment impact zone model, WASP4, may be used to predict natural recovery, and is particularly appropriate where there are ongoing sources of permitted sediment impact zones in the vicinity of the sediment recovery zone. These two methods for predicting natural recovery are described below.

SEDCAM

The concentration at some time after natural recovery begins may be estimated using the following equation:

$$C = \frac{M}{(M+kS)} \times C_p \times \left[1 - e^{\frac{(kS+M)t}{S}}\right] + C_o \times e^{\frac{-(kS+M)t}{S}}$$

where:

C = concentration of a contaminant in sediments at time t (mg/kg)

M = rate of deposition (gm/cm^2-yr)

S = total accumulation of sediments in the mixed layer during the period under consideration (gm/cm^2)

k = combined first-order rate constant for contaminant loss through decay and diffusion processes (yr^{-1})

C_p = concentration of the contaminant in particles being deposited on the sediments (mg/gm)

t = natural recovery time period (years)

C_o = initial concentration in surface sediments (mg/kg).

Deposition rates may be calculated using ^{210}Pb or similar studies performed during the cleanup study (for examples, see Tetra Tech 1988, Appendix A; Hart Crowser 1989), or deposition rates may be estimated from the literature (e.g., Carpenter et al. 1985; Lavelle et al. 1986).

The total accumulation of sediments in the mixed layer (S), is calculated using the following equation:

$$S = ML \times d \times (1-p)$$

where:

S = total accumulation of sediments in the mixed layer (gm/cm^2)

ML = the thickness of the mixed layer (cm)

d = the density of particulate material (gm/cm^3)

p = the porosity of the sediments (cm^3/cm^3).

The mixed layer typically ranges from 0 to 25 cm deep, depending on the benthic organisms present and other physical disturbances at the site such as ship traffic. The average density of solid material is typically estimated at 2.5 gm/cm^3, but may range as low as 1.5 gm/cm^3 in sediments with high organic content. The porosity of sediments typically ranges from 0.5 in densely packed sediments to 0.9 at the surface of loose sediments with high organic content.

The combined first-order rate constant (k) for contaminant loss by decay and diffusion processes must also be estimated for each indicator chemical that is being assessed for natural recovery. A summary of field and laboratory methods for estimating k, and a review of the literature pertaining to degradation rates, can be found in Tetra Tech (1987). Because there are many sources of uncertainty and error in estimating k, the lowest estimate of k should be used. In the absence of data, or if a contaminant is not expected to degrade or diffuse significantly in the time frame considered acceptable for natural recovery, a k value of 0 may be used to indicate no loss of the contaminant.

Finally, the concentration of the contaminant in the particles being deposited must be estimated. This concentration may be estimated from the literature describing particle concentrations in major natural sources (e.g., the Puyallup River for Commencement Bay) and from loading data for local sources of contaminants. Alternatively, the concentration of contaminants on particles may be estimated using a sediment trap to measure the concentration of particles settling at the site. The use and design of sediment traps are described in U.S. GOFS (1989) and Norton (1990). Methods of analysis of particulate samples are described in Tetra Tech (1986).

WASP4

WASP4 is a model used by Ecology to predict the effect of wastewater discharges on sediments and to develop permits for sediment impact zones around NPDES-permitted wastewater discharges. WASP4 is capable of modeling a wide variety of processes affecting contaminant levels in sediments, including source loading, mixing in the water column and sediments, sediment transport, biodegradation, diffusion of contaminants over the sediment-water interface, and natural deposition of sediments. Because of these capabilities, WASP4 is ideally suited for predicting natural recovery of contaminated sediments at a site or within a sediment recovery zone. Compared to SEDCAM, WASP4 requires a relatively large amount of input data on the environment at the site. However, WASP4 is better able to address complex sites where there may be multiple ongoing sources and/or permitted sediment impact zones that may affect the potential for natural recovery at the site. A detailed discussion of data requirements for WASP4 and types of information that can be obtained from the model runs is presented in *Sediment Source Control Standards Guidance Document* (PTI 1991), available from Ecology's Sediment Management Unit.

The equations presented in this appendix, or a similar method, can be used to estimate the recovery rates associated with individual contaminants at a site. The recovery rate can, in turn, be used to estimate 1) the maximum concentration of a contaminant that will recover to a cleanup standard in 10 years or 2) the steady-state concentration (i.e., the lowest concentration) that can be reached through natural recovery at a site given a set of ongoing sources of contaminants to the site.

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APPENDIX D

Cleanup Action Alternatives for Contaminated Sediments

CLEANUP ACTION ALTERNATIVES FOR CONTAMINATED SEDIMENTS

Potential general response actions, cleanup technologies, and process options for contaminated sediments are shown in Figure D-1. Typical cleanup action alternatives that have been considered and evaluated for use at contaminated sediments sites in Puget Sound and elsewhere are described below [summarized from Tetra Tech (1988)]; more detailed discussions of cleanup action alternatives for sediments can be found in Tetra Tech (1988), PSDDA (1986), NRC (1989), Parametrix (1989, 1990), and U.S. COE (1985).

NO ACTION

The no action alternative provides a baseline against which other cleanup action alternatives can be compared. Under this alternative, the site remains unchanged, and nothing is done to mitigate existing impacts to human health and the environment. No source control measures are implemented beyond those required under existing regulatory programs. Natural recovery of contaminated sediments, in the absence of ongoing sources, would be expected to provide some improvement in the level of contamination at the site.

INSTITUTIONAL CONTROLS

Institutional controls include access restrictions, limitations on recreational use of nearshore areas, issuance of public health advisories, monitoring to evaluate changes in sediment characteristics, and most importantly, enhanced regulatory control of contaminant sources specifically oriented toward mitigation of sediment contamination. Limitations on access and recreation (e.g., fishing and diving) reduce human exposure and risk to public health, but do not mitigate existing environmental impacts. Some degree of long-term mitigation is expected as a result of reduction in source loading. Sediment monitoring should be included as part of this alternative to permit identification of contaminant migration patterns and assess sediment recovery associated with source control. Institutional controls may be combined with any of the other cleanup action options.

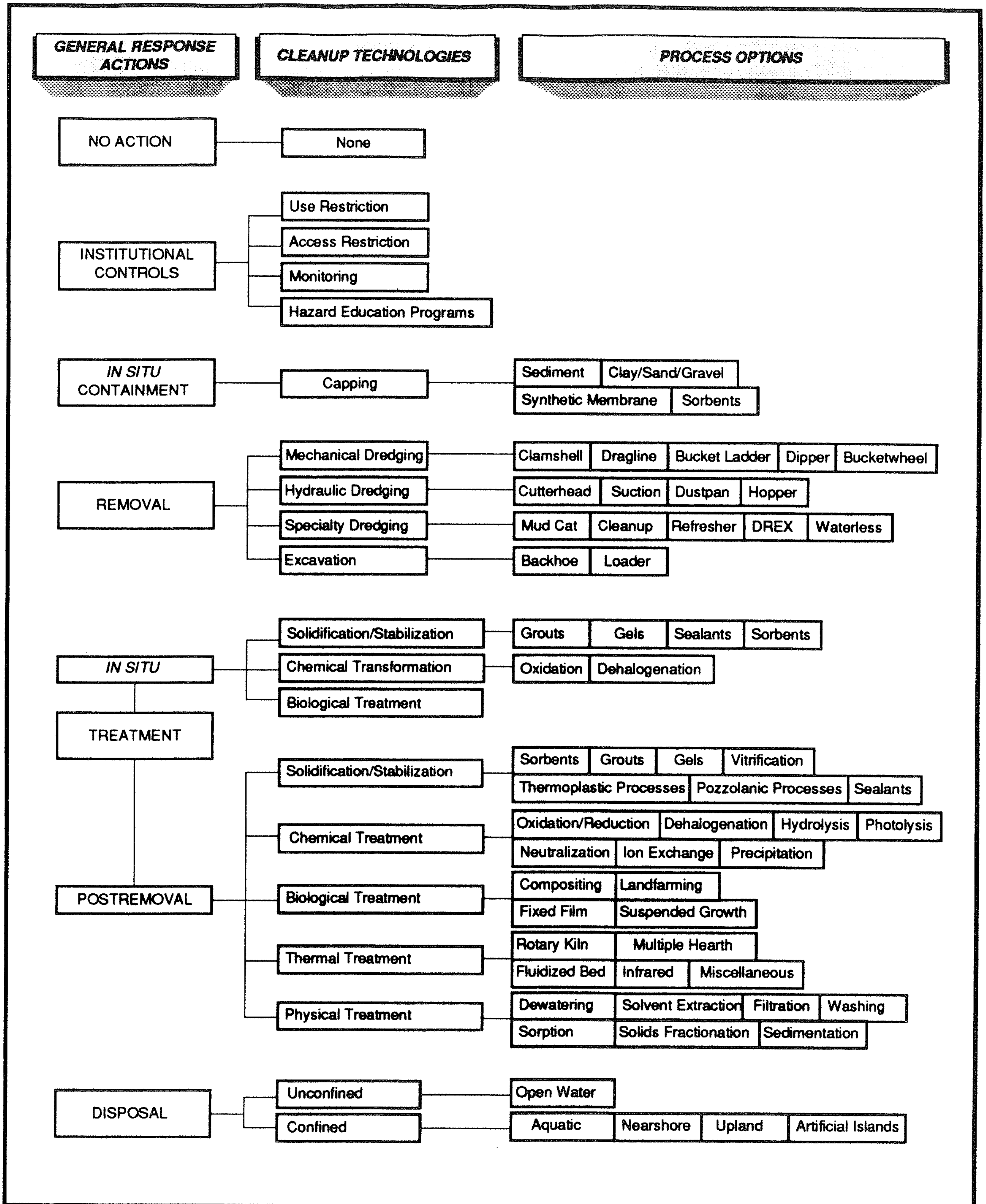

Figure D-1. Selected general response actions, cleanup technologies, and process options for sediments.

IN SITU CAPPING

In situ capping involves containment and isolation of contaminated sediments through placement of clean material on top of existing sediments. The capping material may be clean, dredged material or fill (e.g., sand). In addition, it may be feasible to include synthetic membranes or additives (e.g., bentonite) to reduce the hydraulic permeability of the cap or sorbents to inhibit contaminant migration. Either mechanical or hydraulic dredging equipment can be used for *in situ* capping operations. Cohesive, mechanically dredged material could be placed using a split-hulled barge. Hydraulically dredged material could be placed by using a downpipe and diffuser. Depending on site topography, diking may be necessary along the margin of the capped sediments to provide support for the cap.

IN SITU TREATMENT

In situ treatment methods are innovative and have not been used extensively in the United States. Possible methods of treating contaminated sediment in place include enhanced biodegradation, chemical treatment, and solidification. Enhanced *in situ* biodegradation uses injection of nutrients and control of temperature, pH, and other parameters affecting biological activity to enhance the natural degradation of organic contaminants in sediment. This process has been used extensively for soil and groundwater applications, but has not been applied to sediment sites.

Possible methods of *in situ* chemical treatment include ultraviolet ozonation and chemical dechlorination. For submerged sediments, implementation of a chemical treatment process is complicated by overlying water and the need to till chemical reagents into the sediment. More than one treatment step might be required, and undesirable byproducts of degradation could be produced. In addition, contaminants may be mobilized during tilling.

Solidification and stabilization technologies have been used in Japan to stabilize sediments, but have not been tested for use in remediation of contaminated sediments. However, *in situ* stabilization of sediments could be used in conjunction with capping to reduce the potential for dispersive migration of contaminants associated with sediments.

REMOVAL WITH CONFINED AQUATIC DISPOSAL

Several alternatives for confined aquatic disposal may be included in the cleanup study. These alternatives include shallow-water confined aquatic disposal, open-water confined aquatic disposal, and open-water mounded confined aquatic disposal. These alternatives differ from one another based largely on location, depth, and physical characteristics of the disposal site. Features of a shallow-water confined aquatic disposal site are illustrated in Figure D-2.

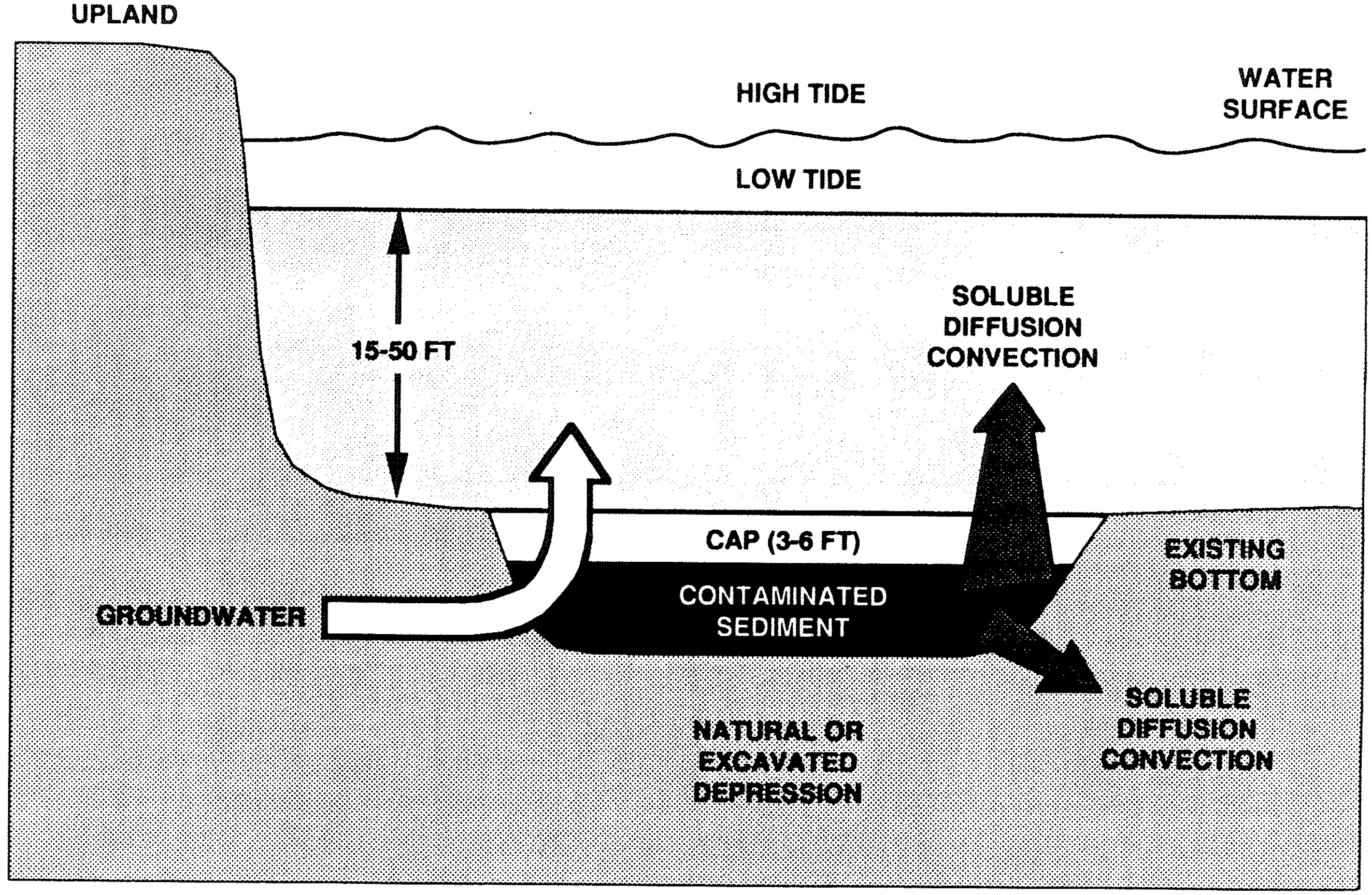

Figure D-2. Confined aquatic disposal of contaminated sediments.

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Mechanical dredging followed by split-hulled-barge placement techniques can be used to implement this alternative. The thickness of the cap required for confined aquatic disposal options ranges from 3 to 6 feet, depending on wave and tidal energies and water depth at the disposal site. Onsite confined aquatic disposal may be implemented within a designated shipping area. This alternative would require dredging well below the zone of contamination, depositing contaminated dredged material in the excavated pit, and capping it with a thick layer of clean, dredged material, particularly if future navigational dredging is anticipated.

REMOVAL WITH NEARSHORE DISPOSAL

Dredging followed by confined disposal in the nearshore environment is another alternative for sediment cleanup. Generally, nearshore sites are diked before receiving dredged material. There are essentially no limitations in the selection of dredging and transport equipment, although hydraulic dredging followed by pipeline transport to the disposal facility is typically considered optimal. Hydraulic dredging confines dredged material to a pipeline during transport, minimizing exposure potential and handling requirements. For sites within 2 miles of a disposal site, a hydraulic dredging system would be possible. Logistical problems may be encountered, however, in areas with heavy marine traffic. Dredging with a clamshell system could be used for sites more than 2 miles from a disposal site.

A schematic drawing depicting general features of a nearshore confined disposal facility is presented in Figure D-3. Systems for managing and treating dredge water can be readily incorporated into the facility design. To accommodate a dredging effluent control system using chemical flocculation, the secondary settling basin might resemble that illustrated in Figure D-4. Typical design features include a fill depth of 30 feet and a minimum cap thickness of 3 feet. Additional capping material may be required if subsequent construction over the confinement facility was planned.

REMOVAL WITH UPLAND DISPOSAL

Dredging followed by upland disposal would involve the transfer of dredged material to an upland disposal facility. Sediment could be dredged either mechanically or hydraulically and transferred to the disposal site by truck, rail, or pipeline. As in the case of nearshore disposal, this alternative can be implemented using standard dredging and transport equipment that is generally used for similar operations. Provisions would be required for the management of dredge water and leachate generated during the dewatering process. Disposal site design features generally include a liner and a cap. The liner system may include an underdrainage system for dewatering the fill material and for controlling leachate over the long term. The underdrainage system could be designed to operate as either a passive collection system or a vacuum-assisted dewatering system.

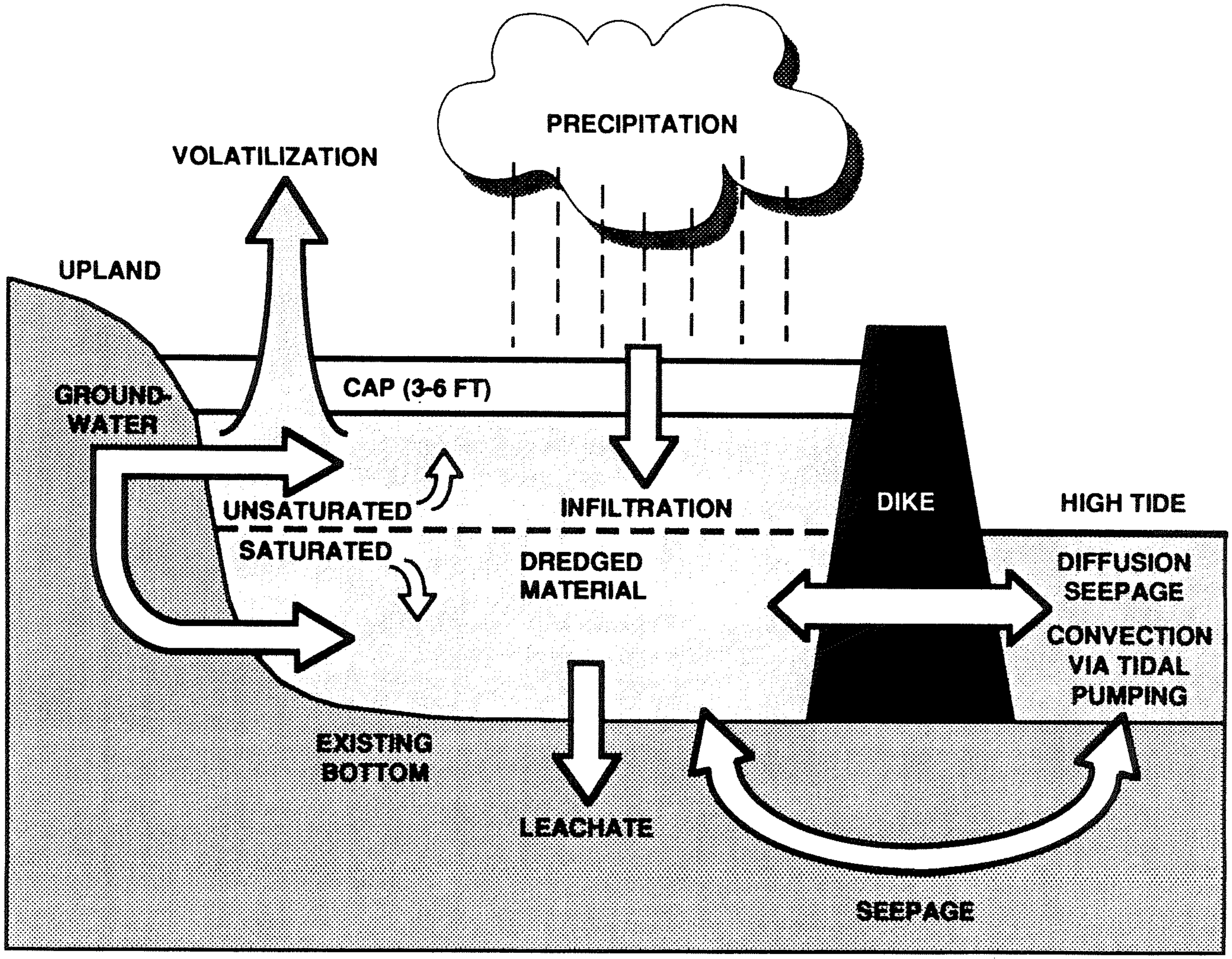

Figure D-3. Confined nearshore disposal of contaminated sediments.

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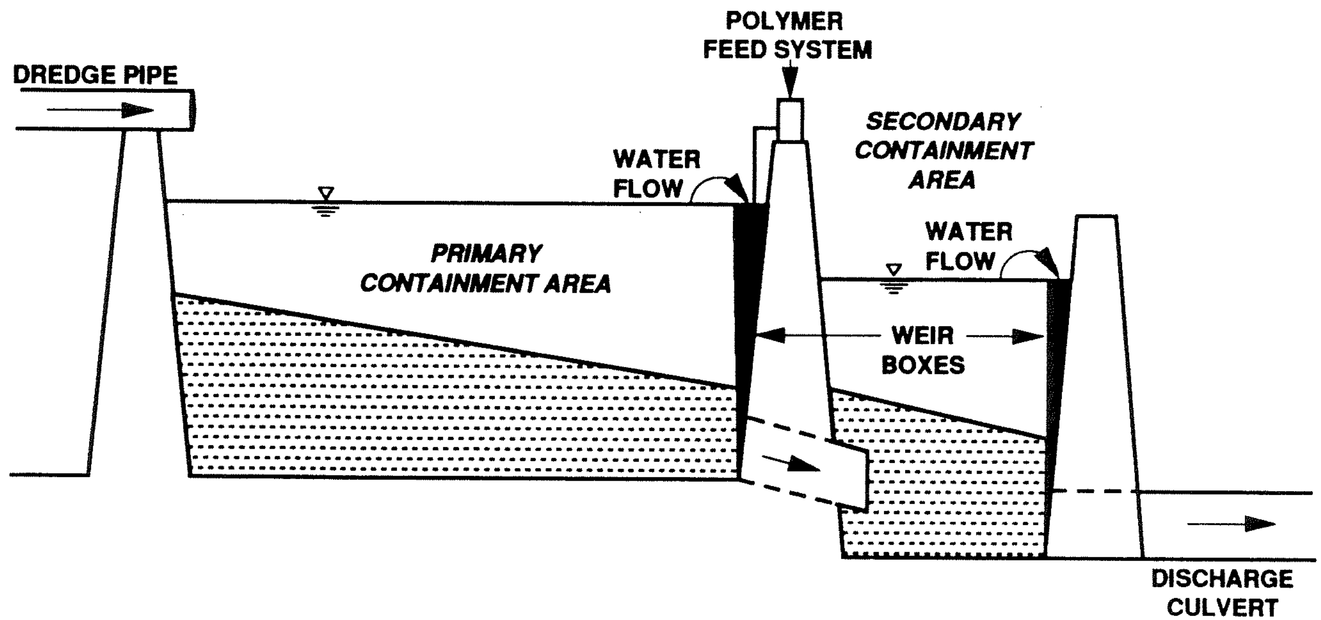

Figure D-4. Dredging effluent chemical clarification facility.

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A schematic drawing of an upland confinement facility is presented in Figure D-5. Dredge water clarification (e.g., using the secondary settling basin and chemical clarification design shown in Figure D-4) would be an essential feature of the facility. A dual synthetic liner and passive underdrainage system should be included to permit removal of percolating dredge water and allow for long-term leachate collection. Dredged material would settle, and ponded dredge water would be removed. Passive collection of percolating water would continue until the fill consolidates to an extent that allows capping operations to commence. The upland landfill may be lined with a synthetic liner material or clay and may have an underdrainage system. All design specifications should be in compliance with federal and state regulations concerning landfills; detailed requirements for disposal of contaminated sediments are under development by Ecology.

REMOVAL, TREATMENT, AND UPLAND OR NEARSHORE DISPOSAL

Treatment of contaminated sediments, in conjunction with removal and upland or nearshore disposal, is one alternative for cleanup action at a site. Potential treatment technologies include solidification, incineration, and solvent extraction. Several solidification agents are feasible for this treatment alternative, but none has been field-tested with marine sediments. Most of the dredge water would have to be removed prior to blending in the solidification agents. Disposal options and landfill design for containment of the solidified material would depend on the hazard level of the solidified sediment and the potential for contaminants to migrate out of the solidified material.

Although incineration permanently eliminates organic contamination in sediments, this alternative has limited application to many sites for two reasons. First, some sites are characterized by significant metals contamination, which is not affected by incineration. Second, most marine sediments do not burn easily, making incineration energy-intensive and less cost-effective. Although there are no permitted incinerators for hazardous waste in the Puget Sound region, it may be possible to locate a portable incinerator near the site, eliminating the need for overland transport of sediments.

For sediments containing primarily organic contaminants, solvent extraction followed by incineration of the organic concentrate may be a feasible alternative. This approach to sediment cleanup results in permanent removal and destruction of organic compounds. The contaminated dredged material would be treated, dried, and transported to an upland or nearshore disposal facility. Effluents from the process include wastewater, treated solids, and a concentrated organic waste that might require additional treatment. Solids retain a low residual concentration of solvent, and depending on metals content, may be returned to the removal site for unconfined disposal, placed in a PSDDA open-water disposal site, or placed in a secure landfill. The extracting solvent, typically triethylamine, is not a listed

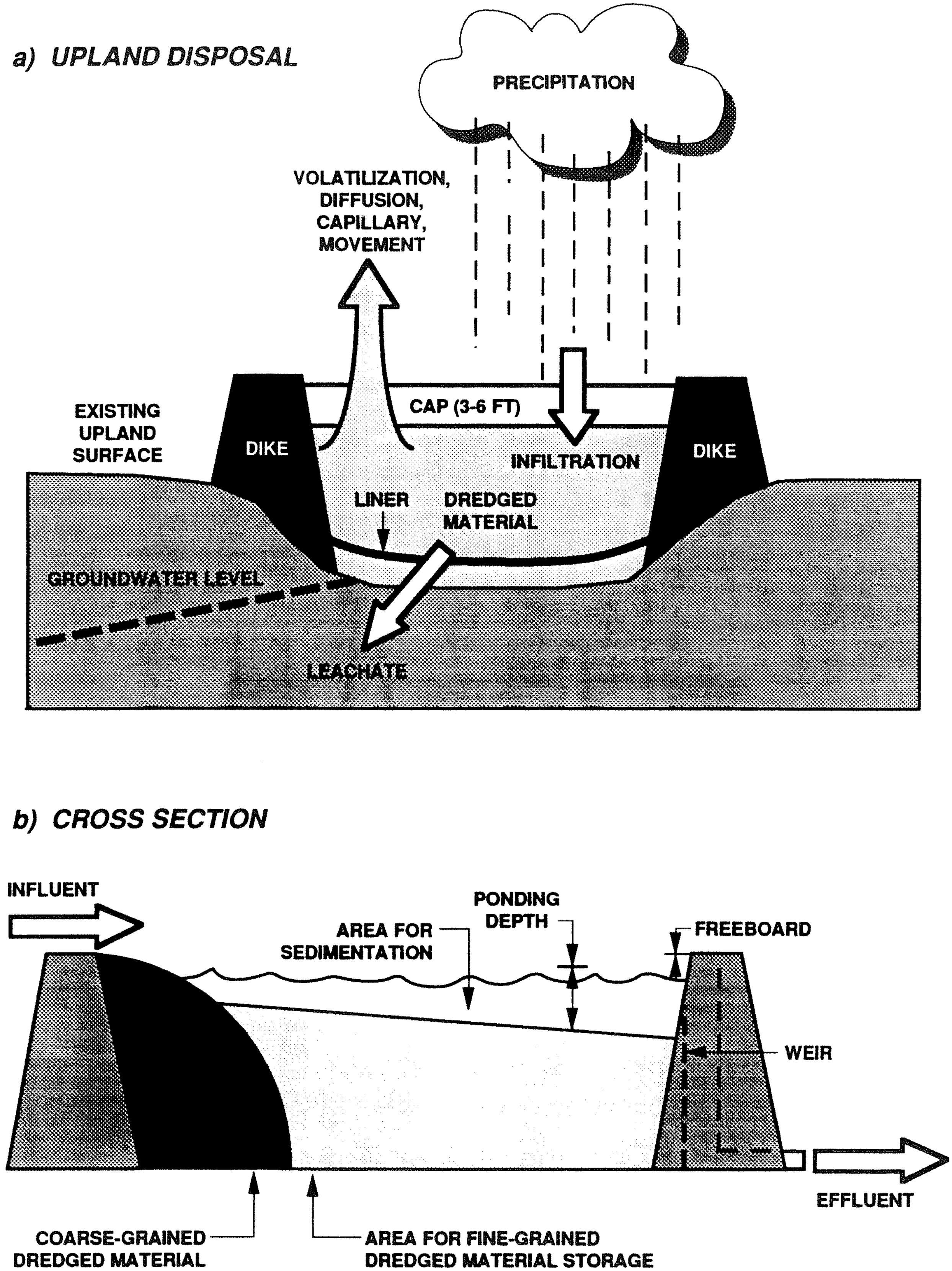

Figure D-5. Confined upland disposal site (a) and cross section of a typical diked upland disposal site (b).

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hazardous waste constituent, which simplifies waste solids and wastewater disposal after treatment.

REMOVAL WITH LAND TREATMENT

Land treatment is a feasible alternative for sediments contaminated with biodegradable organic compounds. Land treatment involves incorporating waste into the surface layer of soil, followed by management of the treatment area to optimize biodegradation by natural soil microorganisms. Chemical and physical characteristics of the waste need to be evaluated to determine the amount that can safely be loaded onto the soil without adversely impacting groundwater. Soils possess substantial cation-exchange capacity, which can effectively immobilize metals. Therefore, wastes containing metals can be land-treated, but careful consideration of the assimilative capacity of the soil for metals is essential. The design of the land treatment facility should prevent stormwater run-on and allow collection and management of runoff. Lysimeters and monitoring wells should be installed and periodically sampled to aid in the detection of contaminants in groundwater.

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APPENDIX E

Overview of the Total Value Approach

CONTENTS

1. INTRODUCTION

The total value approach to setting a site-specific cleanup standard balances the cost of a cleanup action against the action's net environmental effects. This approach seeks to find the site-specific standard that maximizes the total value of the site's environment. Both the costs and benefits of an action must be translated into dollars before this approach can be used. This requirement does not mean that only market effects (e.g., environmental impacts on commercial fisheries or tourism) are considered. It does mean, however, that the various environmental effects of a cleanup action must have a dollar value attached to them. If this is possible, the dollar benefits of different cleanup standards can be compared to their dollar costs, and an optimal standard—the standard that maximizes total value—can be determined.

This appendix illustrates the use of the total value approach to set site-specific cleanup standards. The first section describes the total value approach in the context of setting a site-specific standard for a hypothetical cleanup site, Twin Peaks Bay. The second section introduces some of the basic economic concepts that form the foundation of this approach. The final section outlines how the total value approach can be implemented in setting a site-specific cleanup standard. Appendix F analyzes the total value approach in greater technical detail.

2. SELECTION OF A SITE-SPECIFIC CLEANUP STANDARD: TWIN PEAKS BAY

Twin Peaks Bay is an isolated embayment in northeastern Puget Sound. The bay is shallow and consists of over 1 million square yards of intertidal and shallow subtidal areas. It supports populations of crabs, clams, and sea cucumbers. Clams and sea cucumbers are harvested commercially by several local shellfish companies. The clams are sold to local grocery stores and restaurants, and the sea cucumbers are exported to the Far East. There is a public beach on the bay, which supports recreation such as clam digging, crab harvesting, and wind surfing. There is also a beachfront resort that is popular for its unique views of the Olympic Mountains and the bay's large waterfowl populations.

Historically, the industry in the vicinity has discharged effluents containing metals and organic compounds into the bay. The levels of discharge have been reduced through all known available and reasonable methods of prevention, control, and treatment (AKART), but the remaining levels of contaminants in sediments are sufficient to violate the Washington State sediment quality standards (SQS). Having established that the area qualifies as a contaminated sediment site, Washington Department of Ecology (Ecology) now must choose a site-specific cleanup standard that lies somewhere between the minimum cleanup level (MCUL) and the SQS.

The cleanup study of the bay site revealed a large subtidal area containing sediments that are highly contaminated with mercury. The area with contaminant concentrations above the MCUL is 4,000 square yards; the area with contaminant concentrations above the SQS is 10,000 square yards. The cleanup action will likely consist of capping; the area to be capped will be determined by the site-specific standard chosen.

Three types of data are required in order to use the total value approach to set the site-specific cleanup standard:

1. **Environmental benefits**—The benefits resulting from the improvement of the environment caused by the cleanup action

2. **Environmental costs**—The costs resulting from the degradation of the environment caused by the cleanup action

3. **Direct cleanup costs**—The engineering and materials costs (and transportation and disposal costs, if offsite disposal is used) of the cleanup action.[1]

Each of these three data categories is discussed below in the context of the cleanup of Twin Peaks Bay site.

1. **Environmental benefits**—At present, the level of sediment contamination is not high enough to justify a complete closure of the public beach within the bay, but it is high enough to lower the attractiveness of the area for recreational activity. Although these activities will be further depressed in the first few years following the cleanup, the benthic populations will recover quickly. The ultimately lower levels of contamination are expected to increase recreational visits for clam digging, crabbing, and windsurfing above their current levels, and to increase the demand for the resort's services. Although no ill health effects have been traced to consumption of clams or crabs from this bay, health officials believe there may be a long-term benefit to lowering the level of possible contaminants in these organisms. Finally, many individuals in the region surrounding the bay place a value on a "clean" environment in the bay, even though some of these individuals may never engage in recreation there or even visit the bay.

2. **Environmental costs**—In the short run, the cleanup action has significant negative effects on the bay's benthic populations. As a result, the environmental costs include the economic losses from a temporary closure of the commercial clam and sea cucumber harvesting, and from longer-term restrictions on clam harvesting[2]; the costs also include recreational losses from beach closures and reduced clam and crab harvesting. If the cleanup action has a large visual impact, there may be some economic loss from a reduced demand for the resort's services. These losses increase with the size of the area capped (and hence the site-specific standard chosen).

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[1] Excluded are the costs of a study cleanup plan and report, and monitoring costs. These costs vary with the size of the site but should not vary with the size of a cleanup action for a given site. For this reason, they do not play a role in the total value approach, which considers only costs (and benefits) that vary with the site-specific sediment quality standard.

[2]The area available to commercial clam harvesting might have to be reduced to avoid excessive disturbance of the sediment cap.

3. **Direct cleanup costs**—The direct cleanup costs of the action depend on the amount and type of cleanup. In the case of Twin Peaks Bay, capping has been chosen as the cost-effective cleanup method; the cost of capping is approximately constant at $25 per square yard.[3]

The total value approach attaches dollar values to the environmental benefits and costs, and direct cleanup costs, of a given cleanup action. This means that for each site-specific standard under consideration, the environmental effects of the corresponding cleanup action must first be quantified, not just identified, and then these effects must be assigned dollar values. In this way, the total value—net environmental benefits minus direct cleanup costs—can be calculated for any site-specific cleanup standard.

The total value approach is most easily applied to a limited number of alternatives.[4] For the cleanup of Twin Peaks Bay, the alternatives considered for site-specific standards include MCUL, SQS, and an intermediate standard, SQS_{10}. The cleanup costs and economic effects of cleanup to each alternative standard are listed in Table 1. This table also lists the total value of each standard. For these three alternatives, SQS_{10}, the intermediate action, is the preferred choice.

TABLE 1. THE TOTAL VALUE OF THREE ALTERNATIVE SITE-SPECIFIC CLEANUP STANDARDS

Site-Specific Cleanup Standard	Area (yd^2)	Direct Costs (1)	Environmental Costs (2)	Environmental Benefits (3)	Total Value [3 − (1 + 2)]
$MCUL_{10}$	4,000	$100,000	$25,000	$130,000	$5,000
SQS_{10}	7,000	175,000	50,000	300,000	75,000
SQS_0	10,000	250,000	80,000	375,000	45,000

As illustrated by Table 1, application of the total value approach is straightforward if the environmental effects associated with a cleanup action can be expressed in dollar values. The usefulness of this approach depends on the ease of quantifying the environmental effects of a cleanup action and assigning

[3]The source for this cost is *Final Economic Impact Statement for the Washington State Sediment Management Standards*, Chapter 173-204 WAC, Washington State, Department of Ecology, December 1990, p. 37.

[4]In theory, a continuum of standards could be considered, ranging from the $MCUL_{10}$ to SQS_0. This manner of using the total value approach is discussed in Section 4 of this memorandum and in Appendix F.

dollar amounts to these quantities, such as those in Table 1. In some cases, these values can be drawn from existing studies; in other cases, original (and expensive) studies must be performed before the total value approach can be used. Methods of assigning dollar amounts are discussed in more detail in Appendix F.

3. ECONOMIC VALUE OF ENVIRONMENTAL SERVICES

The example of Twin Peaks Bay illustrates how the total value approach can be used to choose a site-specific cleanup standard. This section presents a more detailed consideration of some of the economic concepts that underlie this approach. Appendix F provides a more advanced treatment of these concepts.

The total value approach is based on the assumption that the environment provides a variety of services to humans, the values of which can be expressed as dollar amounts. Some of these services are beneficial, such as recreational opportunities, commercially exploitable natural resources, or opportunities for viewing natural sites. Other services are harmful, such as the bioconcentration of toxic substances through food webs. The value of these services can be measured by individuals' willingness to pay for them, even if there is no formal market for the services. For example, an individual who travels 60 miles to a favorite beach-combing site "pays" for the trip by spending time and money traveling to the site.

The services provided by sediment quality are a special case. Few individuals are likely to value sediment for its own sake, although its quality may be an element of an individual's desire for a "clean" environment. Instead, the quality of sediment plays an important role in supporting other environmental services with a more direct value to humans.

These other services can take several forms. In the example of Twin Peaks Bay, sediment quality affects organisms or activities that have *market values*.[5] This type of environmental value can be expressed in at least two ways: the market price, which is an imperfect measure; and *producer surplus*, a more exact measure equivalent to a producer's profits. A significant change in sediment quality may affect the numbers or quality (i.e., levels of contamination) of marketable organisms such as clams and sea cucumbers. These effects may result in changes in market prices or producers' surplus. The cleanup action also can change market prices or producers' surplus through reductions in the population of marketable organisms, or restrictions on the production of marketable activities. For consumers, the change in sediment quality and the consequential environmental effects can affect *consumer surplus*, the difference between the value of a good and its price. Changes in consumer and producer surplus are accurate measures of changes in the market values derived from environmental services.

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[5]Italicized phrases are defined and discussed in greater detail in Appendix F.

The sediment quality in Twin Peaks Bay also affects environmental services that are not marketed, or *nonmarket values*. Recreational activities such as clam and crab harvesting and windsurfing exist outside a formal market (i.e., these activities are not bought and sold). There are a number of methods for estimating this type of value. For environmental services such as recreation that require a trip to a natural site, the *travel cost method* estimates the demand for recreation (or some other service), and from this, an estimate is made of recreational value (in terms of consumer surplus). Another method, the *contingent value survey method*, uses a survey questionnaire to determine an individual's valuation of (or willingness to pay for) a potential change in the level of an environmental service or in environmental quality. Research has shown that this method is capable of accurately measuring individuals' environmental values, despite the hypothetical nature of the survey. In addition to these two major methods, there are other methods that can be used; however, these methods are either less applicable to measuring the value of environmental services or are less accurate. These methods are discussed in more detail in Appendix F.

The methods for estimating nonmarket values can be applied to the long-term benefits from a cleanup action, or to the short-term costs of that action. For example, a travel cost study could estimate the demand for clam digging at Twin Peaks Bay's public beach as a function of the cost of traveling to the beach and the "quality" of the clams.[6] In the short run, the cleanup action reduces the supply of clams; the cost of this reduction can be expressed as a decrease in the consumer surplus from clam digging, derived from the estimated demand function. In the long run, the cleanup action restores the supply of clams and improves their quality; the value of these benefits also can be derived from the estimated demand function.

Finally, individuals may value environmental quality for its own sake, or they may value a unique natural site despite the fact that they never visit the site. These *non-use values* are based on the value of preserving the environment independent of any use. This type of value can be estimated only with a contingent value survey.

Because a cleanup action has effects that extend over time, there are two additional issues that arise in using the total value approach. First, the estimated values need to be adjusted to account for the distribution of the effects over time. This process, called discounting, places decreasing weight on dollar values that occur in the future, giving present benefits and costs the greatest importance. For example, if a beach is closed to clam digging for 5 years rather than 1 year, the dollar damage is not 5 times as high. Instead, the present value of each future year's closure is less than the value of the present year's closure.

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[6]To estimate the relation between demand and quality, some variation in quality over time or within the bay would be necessary.

A second, more complicated issue is the presence of uncertainty. If the effects of a cleanup action extend over time, there can be uncertainty over the type and level of these effects. This uncertainty can have two sources: ecological effects that are determinable only over time, and economic effects that may vary over time because of changes in income, tastes, market or nonmarket conditions, and so forth.

The economic approach to measuring environmental values in the presence of uncertainty is still evolving. The major adjustment that must be made is to incorporate uncertainty into the economic models of behavior that underlie the method(s) used to estimate environmental values. For example, a contingent value survey that elicits individuals' willingness to pay (today) for a cleanup action with uncertain future effects should outline the sources and types of uncertainty as part of the survey questionnaire.

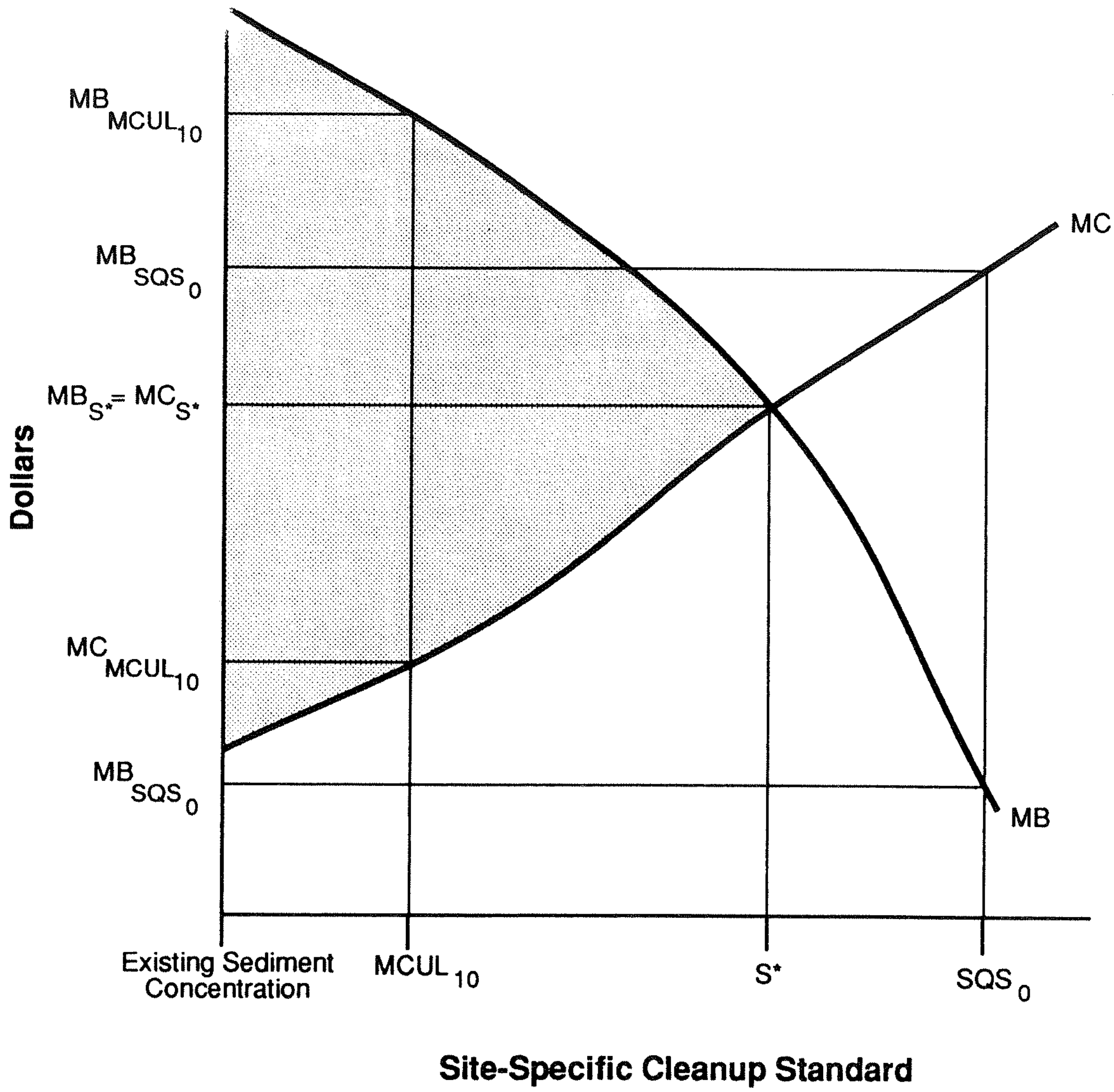
These two complications make estimating the values of environmental services more difficult, but not impossible. The total value approach must have a fairly complete set of estimated values; the next section outlines the mechanics of the approach assuming that this complete set of values exists.

4. USING THE TOTAL VALUE APPROACH

The total value approach attempts to maximize the net economic benefits of choosing a site-specific cleanup standard, where the net economic benefits equal the net environmental benefits minus the direct cleanup costs. The net economic benefits are calculated for each site-specific standard under consideration. This can be done by constructing a limited number of alternatives, or by constructing mathematical functions based on 1) biological models of the relations between sediment quality and environmental effects, and 2) economic studies of the dollar values of those effects.

In general, the net benefits of an action will rise if the additional or *marginal benefits* of increased action outweigh the additional or *marginal costs*. For sediment quality, a stricter standard is desirable as long as the marginal environmental benefits outweigh the marginal environmental costs and direct cleanup costs. In Table 1, for example, the marginal benefits of going from $MCUL_{10}$ to SQS_{10} equal \$170,000; the marginal costs equal \$100,000. The total value approach therefore judges the stricter standard, SQS_{10}, to be a better standard. The marginal benefits of going from SQS_{10} to SQS_0 (\$75,000), however, do not outweigh the marginal costs (\$105,000), and the total value approach judges SQS_{10} to be a better standard than SQS_0.

If the benefits and costs can be expressed as continuous functions of the site-specific standard, a more accurate analysis is possible. In Figure E-1, MB is the marginal benefit of increasing the site-specific standard above the current level of sediment quality. (Along the horizontal axis, "0" represents the current quality level.) MC is the marginal cost (environmental and direct cleanup) of choosing a more stringent standard. At the $MCUL_{10}$, the marginal benefits of increasing the standard, $MB_{MCUL_{10}}$, exceed the marginal cost, $MC_{MCUL_{10}}$. The total value approach dictates the choice of an optimal standard more stringent than the $MCUL_{10}$. At SQS_0, MB_{SQS_0} is less than MC_{SQS_0}, which dictates an optimal standard less stringent than the SQS_0. At S*, the marginal benefits and marginal cost are equal; this site-specific cleanup standard therefore maximizes the total value (or net economic benefits). In this way, if exact formulations of benefits and costs are possible, the total value approach can be used to choose the optimal standard from the range of all allowable standards.



LEGEND

MB	Marginal Benefits
MC	Marginal Costs
$MCUL_{10}$	Minimum Cleanup Level (to be achieved in 10 years)
SQS_0	Sediment Quality Standard (to be achieved now)
S*	Site-Specific Cleanup Level

Figure E-1. Choosing an optimal site-specific standard.

5. SUMMARY

The total value approach seeks to find the site-specific cleanup standard that maximizes the net economic benefits of the cleanup action. Because the environmental effects of the action must be translated into economic values, this approach is difficult and expensive to use. Choosing the optimal standard from a continuum of standards requires explicit mathematical models of the relations between sediment quality and environmental effects, and between those effects and economic values. Choosing the best standard from a finite number of alternatives is less difficult, particularly for comparing some logical alternatives such as $MCUL_{10}$, SQS_0, and the intermediate standards $MCUL_0$ and SQS_{10}.

APPENDIX F

Implementing the Total Value Approach

CONTENTS

1. INTRODUCTION

The total value approach places economic values on the effects of a cleanup action. Some of these values can be measured directly. For example, the cleanup action has engineering and materials costs that are easily estimated. It also may necessitate the closure of commercial resource operations, resulting in lost profits. Most of the effects, however, lie outside formal markets and are most easily measurable in physical terms, such as numbers of benthic organisms destroyed (a short-term effect) and reduced levels of contamination in those organisms (a long-term effect). The total value approach uses the economic values of these environmental effects to choose the optimal cleanup standard for a contaminated sediment site.

Sediments support a variety of aquatic and terrestrial populations. They also contribute to (or detract from) the quality of marine waters, which support other types of populations. The health of these populations is related to the levels of contamination or quality of the sediments. The health of the human population may also be affected indirectly by these contaminants. As higher organisms consume contaminated lower organisms, the contaminants become concentrated. If humans consume these higher organisms, such as shellfish and anadromous and demersal fish, there is a risk of adverse health effects.

Sediment quality has no directly measurable economic value. Instead, its value is determined indirectly by two factors:

- The strength of the relations between sediment quality and the health of related ecological communities, and between sediment quality and environmental amenities in general
- The magnitude of the economic values associated with the ecological communities or other amenities supported by sediment quality.

The focus on economic values is important. Even if a strong relation exists between sediment quality and environmental resources or amenities, the absence of any economic value of these resources or amenities implies the absence of any economic value for sediment quality.

This appendix is a detailed presentation of the total value approach. It is divided into two major sections. The first section discusses the general problem of measuring environmental values in terms of dollars. If this problem can be solved, the total value approach can be used to establish a site-specific cleanup standard. A detailed presentation of this approach is the subject of the second section.

2. VALUATION OF ENVIRONMENTAL SERVICES

The environment is the source of a variety of economic services beneficial to humans. The most direct set of services is the flow of resources used in the production of market goods, such as commercial fisheries; additional services include the recreational opportunities or other nonmarket services provided by natural sites such as forests, wetlands, and water bodies. Sometimes the mere existence of a unique natural resource provides a valuable "service." This section considers different means of placing a dollar value on these services.

The valuation of environmental services relies on the assumption that individuals are willing to exchange money for an improvement in environmental quality or accessibility. This view is embodied in the economic concept of willingness to pay and its empirical counterparts, producer and consumer surplus. Willingness to pay (WTP) is the maximum amount of money an individual is willing to give up in exchange for a good (or opportunity). For example, the value of a recreational opportunity such as hiking or fishing that requires access to a specific natural site can be measured by an individual's WTP. Given a choice between no access and access at a fee, an individual's WTP is the maximum fee that person would pay to gain access.

There are three types of potential resource services, each of which can exist for the same resource and can contribute to the total WTP for the resource. The first type is market services, or the services derived from a resource in a market setting. The second type is nonmarket use of a resource, which comes from enjoying or consuming the resource in its original form. Finally, there are non-use services, where an individual does not visit the resource site but nevertheless values its existence.

2.1 MARKET SERVICES

When a natural resource is traded in a market, the value of that resource's services can be measured in an obvious way: the market price of the resource. The use of market price as an exclusive measure, however, is appropriate only when the following conditions are met:

- A competitive market exists for the resource *in situ*
- The amount of the resource under consideration is "small," or the quality of a resource in fixed supply is under consideration
- The resource has no nonmarket value.

If one or more of these conditions are not met, market price must be modified or abandoned as the sole measure of resource value.

In some cases, a market exists for the resource but not *in situ*. For example, a commercial fisher does not purchase rights to fish directly from the ocean; instead, the fisher bears certain costs in catching fish and bringing them to the landed market. In this case, market price overstates the fish's value to the fisher and must be adjusted downward to reflect the costs of fishing.

If a market exists, *in situ* or not, a large change in the existing supply or quality of a resource necessitates the use of producer and consumer surplus in place of market price. When a resource is sold in a market, the revenue that producers receive is greater than the costs they bear in selling the resource. Similarly, the amount consumers are willing to pay for the resource is greater than the amount they actually pay. These differences are called producer and consumer surplus, respectively.

Figure F-1(a) illustrates how producer surplus can be derived from the market supply curve, S, which can be interpreted as the marginal cost (to the industry) of supplying additional quantities of a good. Given a market price of P_M for a natural resource, the area PS represents the excess of revenue over costs, or producer surplus. This amount measures the amount the industry would be willing to pay to retain their access to the resource. If an improvement in environmental quality creates a new resource supply (e.g., the reestablishment of a salmon run), PS is a measure of the value of this new supply to the resource suppliers.

Short of creating a new source of supply, environmental improvements can affect producer surplus in two other ways. First, if an improvement lowers the cost of supplying the resource, producer surplus will increase (assuming no change in the market price). Second, if the improvement increases the quality of the resource, the market price may rise, increasing producer surplus.

Figures F-1(b) and F-1(c) illustrate these potential changes. In Figure F-1(b), supply costs fall, shifting the market supply curve from S to S′; the quantity supplied rises and producer surplus increases. The value of this change, to the suppliers of the resource, is ΔPS. In Figure F-1(c), the market price rises from P_M to P_M", increasing producer surplus. The value of this change is again ΔPS.

If environmental improvements affect a marketed natural resource, consumers also can enjoy a gain analogous to that enjoyed by producers. This gain is termed consumer surplus. Figure F-2 illustrates how consumer surplus can be derived from a market demand curve. The demand curve, D, represents the maximum amount consumers are willing to pay (per unit) for a given quantity. If the market price is P_M, consumer surplus is then the area between the demand curve, D, and the market price, or the area CS.

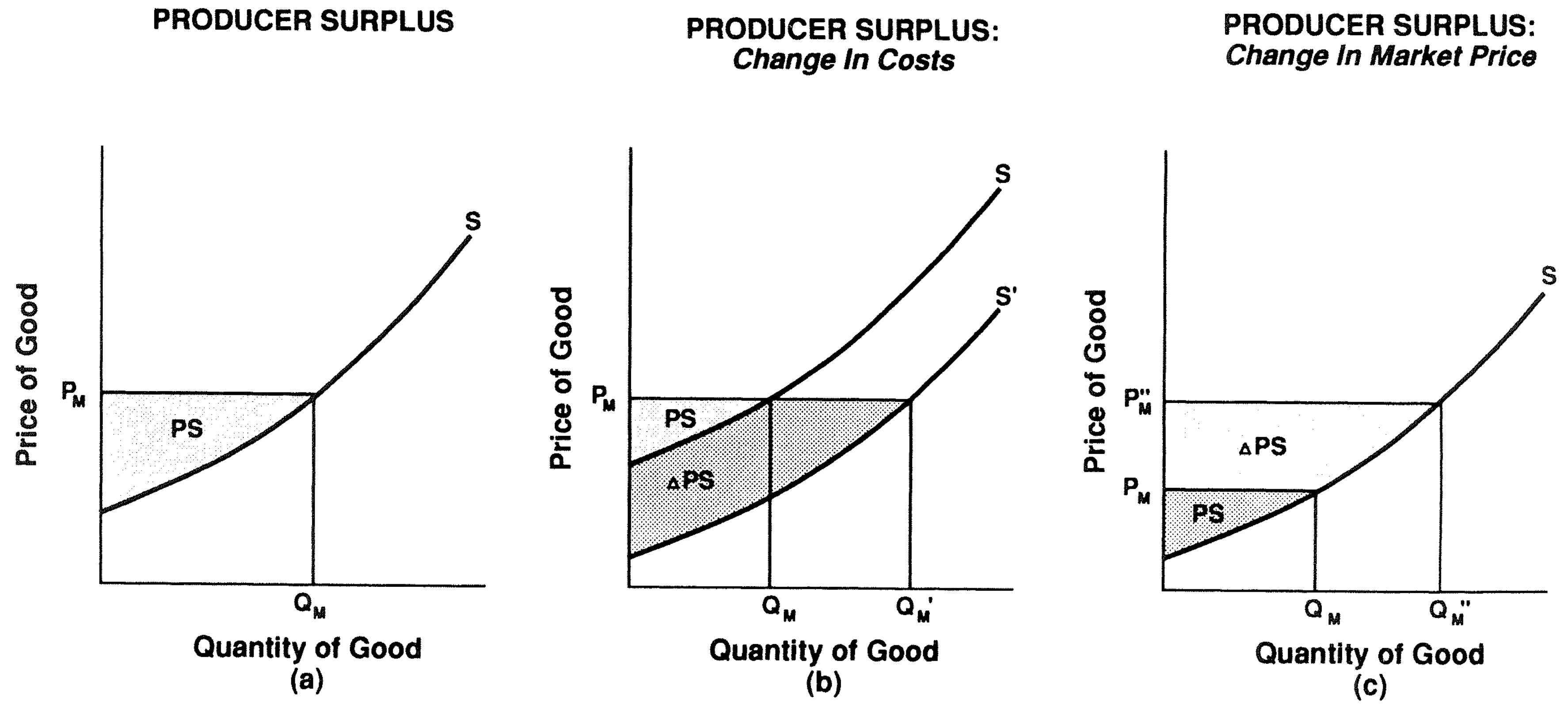


Figure F-1. Producer surplus.

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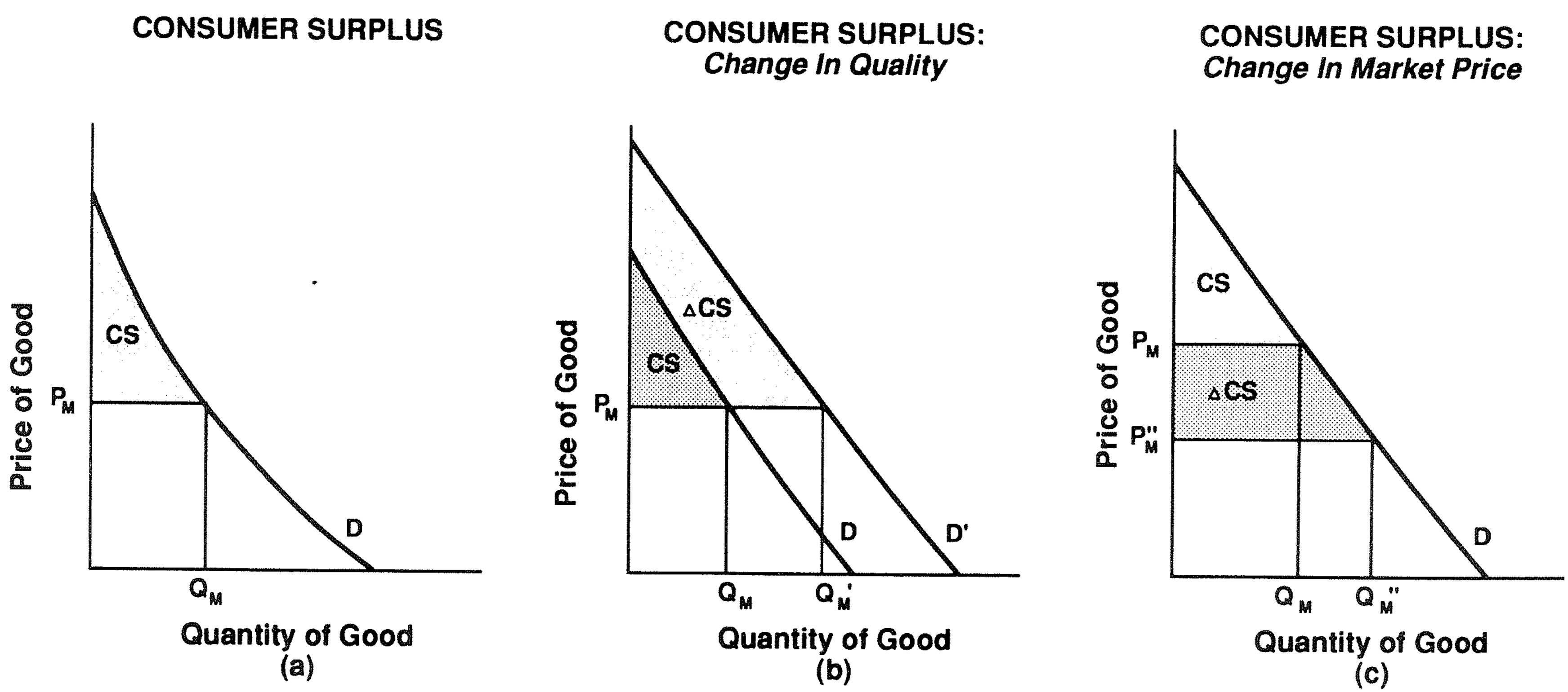

Figure F-2. Consumer surplus.

Consumer surplus also can change, for two reasons. First, if an environmental improvement increases a resource's quality, consumers' WTP will rise, increasing the market demand and consumer surplus (again assuming no change in the market price). Second, consumer surplus will increase if the market price decreases because of, for example, variation in supply costs.

Figures F-2(b) and F-2(c) illustrate the sources of change for consumer surplus. In Figure F-2(b), resource quality increases, shifting the market demand curve from D to D′; the quantity demanded goes up and consumer surplus increases. For consumers, the increase in the value of the resource is then ΔCS. In Figure F-2(c), the market price decreases from P_M to P_M", increasing consumer surplus. The consumer value of this change is ΔCS.

Sufficient environmental improvement will disturb the equilibrium of a resource market, changing both producer and consumer surplus. Figure F-3 illustrates the case where the improvement increases the quality of the resource. The initial market equilibrium is at point E, with P_M and Q_M the market price and quantity, respectively. The improvement shifts the demand curve from D to D′, increasing the market price to P_M' and the quantity sold to Q_M'. Consumer surplus increases to the area A′E′P_M', and producer surplus increases to CE′P_M'.

For these applications of market value, the most important assumption is that the market reflects the whole value of the resource. If this is not the case, market price will be a poor measure of the resource's value.

2.2 NONMARKET RESOURCE USE

If a market does not exist for a resource, the resource may still provide valuable services. Although the discussion of consumer surplus in the previous section is in terms of market goods, the concept also applies to nonmarket goods. In either case, the concept of consumer surplus is central to measuring the value of nonmarket resources.[1]

For example, many individuals enjoy digging clams along beaches. These people do not make any direct market purchase (e.g., a paid clam safari) but they do sacrifice something of value (e.g., travel expenses and time) to "consume" clam digging. Thus, it is feasible to determine their WTP and consumer surplus for clam digging even though no clam digging market exists.

For example, an individual is asked to name the maximum dollar amount she would sacrifice to enjoy one day of clam digging at a given beach; our hypothetical individual answers "$20." This question is repeated for additional

[1]Because nonmarket natural resources do not have a supply side, producer surplus does not apply.

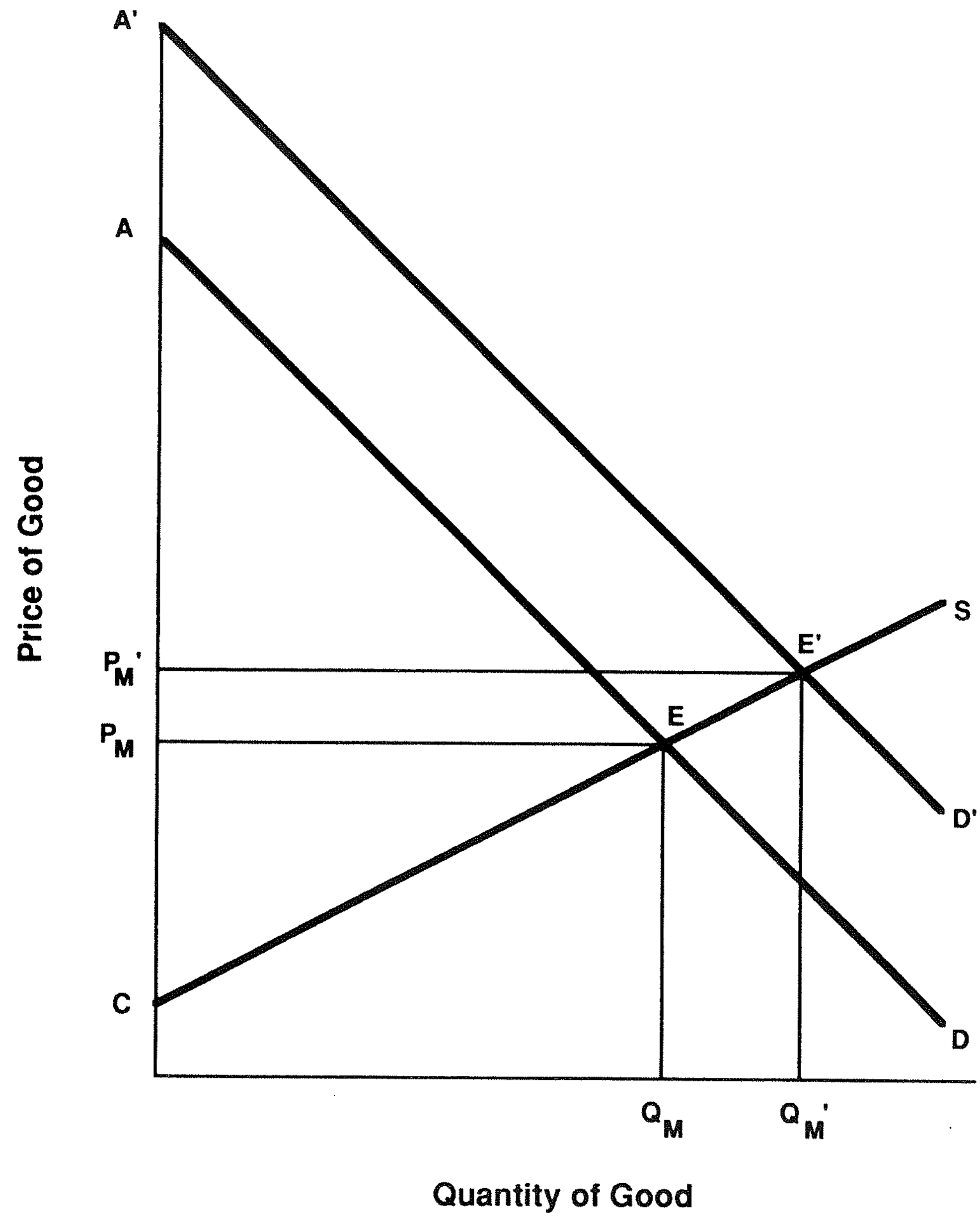

Figure F-3. Change in producer and consumer surplus.

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days to be "consumed" over a single season. Table F-1 offers a schedule of hypothetical answers. This schedule is equivalent to a "demand" schedule for days of clam digging, where the "price" of a clam digging day is akin to a beach access fee. Now suppose the cost of clam digging for this individual is \$6 per day. The number of days chosen (per season) will be four (i.e., 4 days for which WTP exceeds the daily cost), resulting in a consumer surplus of \$34. If the beach is closed to clam digging for one season, this amount would be the economic loss suffered by our hypothetical individual.

TABLE F-1. WTP: CLAM DIGGING

Days of Clam Digging	Willingness to Pay (\$)	Consumer Surplus[a]
1	\$20	\$14
2	17	11
3	13	7
4	8	2
5	2	--
6	0	--

[a] The calculation of consumer surplus assumes a cost per day of \$6.

As in the market case, the consumer surplus associated with the use of nonmarket resources can change for two basic reasons: a change in resource quality, or a change in the cost of "using" the resource. If a decrease in sediment contamination improves the quality of clams (in the long run), the WTP for clam digging will rise, increasing consumer surplus. Alternatively, if access to the beach becomes more restricted, increasing the cost of engaging in clam digging, the resulting change in consumer surplus would be negative.

A natural resource does not have to be used directly to provide nonmarket resource services. For example, plankton populations are a major contributor to the estuarine and marine food web, supporting a number of other resources (e.g., shellfish, birds, marine mammals) that are consumed, viewed, or used in some way by humans. A plankton population provides humans with nonmarket resource services, therefore, that have an indirect or derived value (i.e., the value of plankton is derived from the values of the species that feed on plankton).

Before the derived value of a resource can be measured, there must be knowledge of the use values of these higher organisms and the relations between different levels of the food web or other ecological relations. If a lower organism supports higher organisms that have no market or nonmarket value, or if there is no biological link to higher organisms, the lower organism has no nonmarket resource value, either from direct or indirect use.

2.3 NON-USE VALUES

Economists have drawn a distinction between two types of nonmarket value associated with a resource: **use value**, the value that arises from the enjoyment of the resource *in situ*; and **non-use value**, the value that exists even when an individual does not travel to the resource site. Some federal regulations recognize both use and non-use values. The Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), and the Oil Pollution Act of 1990 (OPA), for example, allow for the inclusion of non-use values in natural resource damage assessments.

There is general agreement that some resources have **existence value**, which captures an individual's valuation of a resource that is present despite the fact that the individual does not travel to or "use" the resource in any way. For example, suppose an individual has no intention of ever visiting the Grand Canyon. That individual may nevertheless be willing to contribute to a fund that helps maintain the existence of the Grand Canyon. If this is the case, the existence of the Grand Canyon, even without direct enjoyment of the resource, has value to that individual.

A similar non-use value is **bequest value**, which captures the value to an individual (today) of preserving a resource for future generations. Bequest value is difficult to separate from existence value because both depend on individual preferences about the preservation of a natural resource. In theory, existence value captures an individual's personal preservation value, while bequest value captures the value an individual places on preserving the resource for future generations. In practice, these two non-use values are difficult to separate because they depend on different motives for the same action—preservation.

Another non-use value is **option value**, the exact nature of which is the subject of much debate among economists. As originally interpreted, option value refers to the amount an individual is willing to pay to retain access to a resource, even if the future use of the resource is uncertain. If an individual has no present plans to visit the Grand Canyon, for example, that individual may nevertheless be willing to contribute to a fund intended to keep the canyon open to the public, based on the possibility of visiting the canyon sometime in the future.

The poorly defined nature of non-use values in general is unfortunate because such values have the potential to generate large estimates of economic benefits. In theory, non-use values are not restricted to individuals who live near or travel to a resource site. For example, the preservation of the Grand Canyon might be valued by all U.S. citizens, not just those who live nearby or visit the canyon.

For this example, an average annual non-use value of \$1 would be equal to over \$240 million per year in benefits from preserving the canyon.

Another concern over non-use values is the difficulty of separating them from indirect or derived use values. Many individuals may express a positive WTP for the preservation of plankton populations, for example. Yet this WTP may be derived from the support these populations provide for other natural resources with use values, not because the plankton populations themselves have existence value. Similarly, the value of a "clean" environment may be based on concerns about health or damage to natural resources that have use value, rather than on the mere existence of the environment in a clean state. The measurement of non-use values, then, must carefully separate the existence of a resource from the possible uses, direct or indirect, that the resource may have.

2.4 DISCOUNTING NET ENVIRONMENTAL BENEFITS

If the effects of an environmental improvement occur over a period of time, the estimated value of the improvement needs to be adjusted to account for the distribution of the effects over time. This process, called discounting, places decreasing weight on dollar values that occur in the future, giving present benefits and costs the greatest importance. For example, if a beach is closed to recreation for 5 years rather than 1 year, the dollar damage is not 5 times as high. Instead, the present value of each future year's closure is less than the value of the present year's closure.

The accepted method for discounting a yearly stream of benefits and costs is given in Equation 1.1:

$$PV = (B_0 - C_0) + \frac{(B_1 - C_1)}{(1+r)^1} + \frac{(B_2 - C_2)}{(1+R)^2} + \ldots \qquad 1.1$$

where:

PV = Present value of stream of benefits and costs;

$B_1 - C_1$ = Net benefits (benefits minus costs) in year i; and

r = Discount rate.

Table F-2 presents an example of how discounting can affect the calculation of the net benefits of an environmental improvement.

TABLE F-2. DISCOUNTING NET ENVIRONMENTAL BENEFITS

	Net Benefits in That Year			
		Discount Rate		
Year After Improvement	Undiscounted	3%	6%	10%
0	100.00	100.00	100.00	100.00
1	100.00	97.09	94.34	90.91
2	100.00	94.26	89.00	82.64
3	100.00	91.51	83.96	75.13
4	100.00	88.85	79.21	68.30
Total	500.00	471.71	446.51	416.98

Alternatively, if benefits and costs can be represented as continuous functions of time, B(t) and C(t), respectively, the method for discounting net benefits from $t=0$ to $t=T$ is given in Equation 1.2:

$$PV = \int_{o}^{T} [B(t) - C(t)]e^{-rt}\, dt \qquad 1.2$$

When federal agencies conduct benefit-cost analyses of projects, their choice of a discount rate is guided by regulations. For example, the recommended discount rate for damage assessments under CERCLA is set by the Office of Management and Budget (1972). This discount rate currently stands at 10 percent and applies to the discounting of benefits and costs for nonwater-related federal projects. Water-related projects are governed by a different set of regulations, listed in U.S. Water Resources Council (1983).

2.5 MEASURING NET ENVIRONMENTAL BENEFITS IN THE PRESENCE OF UNCERTAINTY

The discussion in the preceding sections assumes that the effects of an environmental change are certain; however, this is not always the case. If the effects of a change extend over time, there can be uncertainty over the type, level, and timing of these effects. This uncertainty can have two sources: ecological effects that are determinable only over time, and economic effects that may vary over time because of changes in income, preferences, market or nonmarket conditions, and so forth.

The economic approach to measuring environmental values in the presence of uncertainty is still evolving. As noted previously, the concept of option value was introduced to account for uncertainty over future use. Although the exact nature of this non-use value is still disputed, there is more agreement that a related concept—option price—is a valid measure of resource value when uncertainty is present. Option price measures an individual's WTP for a natural resource or opportunity of uncertain value. For example, cleaning up a hazardous waste site may reduce future health risks. For a given risk reduction, an individual is willing to pay some maximum amount—option price—even though the remaining potential risk is uncertain.

3. METHODS FOR ESTIMATING THE VALUE OF ENVIRONMENTAL SERVICES

There are several methods for estimating the value of environmental services; no single method is preferred to all others. The discussion of these methods below is divided into two types of methods: those capable of estimating the value of market services, and those capable of estimating nonmarket (use and non-use) values. A final section discusses the general applicability, reliability, data requirements, and computational complexity of these methods.

3.1 ESTIMATING THE VALUE OF MARKET SERVICES

If a market exists for a natural resource, the market quantities described in Section 1.1.1 can be estimated directly if sufficient data exist. The **market price method** requires a simple multiplication: price times quantity. Estimating producer and consumer surplus for a market good is more complicated and must be based on an economic model of the resource market. The range of these models begins with simple equations for supply and demand, capable of generating rough estimates of surplus, and increases to sophisticated computer models, which account for substitute markets, producer profit maximization with respect to inputs and multiple outputs, and the technological or quality effects of environmental change.

Another market method is the **appraisal method**, which can be used when the resource that is affected is not marketed, but a comparable resource is. An appraiser then uses standard methods and professional judgement to calculate the value of the resource with and without the environmental change.

3.2 ESTIMATING NONMARKET RESOURCE VALUES

There are three primary methods for estimating nonmarket resource values, although only one of them is capable of estimating both use and non-use values. The most commonly used methods are the **travel cost** and **contingent value survey** methods; a third, the **hedonic** method, is employed less frequently. Other methods include the **factor income**, **expenditure**, **gravity**, and **unit value** methods.

3.2.1 Travel Cost Models

The central thesis of the travel cost method is that the cost of traveling to a natural site can be used as a proxy for the price of "consuming" the services available at that site. Differences in the cost of traveling to a recreation site should then give rise to variation in rates of participation by potential users: i.e., those living closer to a site should visit it more often than similar individuals who live farther away. In short, travel cost can be used to construct a demand curve for the *in situ* services of the site, from which an estimate of consumer surplus can be derived.

The simplest version of a travel cost model relates the number or frequency of visits to the price of a visit. Because no formal market exists, price takes the form of an individual's travel cost, which consists of the out-of-pocket costs of travel and the opportunity costs of the time spent traveling. The simple model focuses on a single site and can be used, for example, to estimate the economic loss from the closure of a public beach after an oil spill. Because this focus severely limits the usefulness of any results, economists have developed advanced travel-cost models that incorporate into the model substitutes (i.e., other types of resources or other resource sites that could be used in place of the site under consideration) and environmental quality. These advanced models produce a demand function that can be used to estimate the consumer surplus associated with changes in a site's characteristics or accessibility.

3.2.2 Contingent Value Surveys

In contrast to the travel cost method, a contingent value (CV) survey estimates the value of a natural resource directly from people's answers to a series of questions. The main appeal of this method is its ability (in theory) to capture resource values in a wide range of situations; e.g., sediment contamination, changes in visibility, improvements in water quality, the opening of a new recreation site, or the provision of a hunting permit. This method has been criticized, however, because in most cases it is impossible to link survey results to actual behavior. This problem is inherent in the method: the research design is aimed at uncovering what individuals would do *hypothetically* if they faced a certain situation.

Most CV surveys consist of three parts. First, the survey provides a description of a hypothetical situation, including the resource or natural site to be valued, the current level of its provision and its level after any hypothetical change, the institutional structure under which the good or service is provided, the range of available substitutes, and the instrument or method of any hypothetical payment or reimbursement (such as an increase or decrease in license fees, taxes, or utility bills), which is referred to as the payment vehicle.

The second part of the survey contains questions designed to obtain the respondent's valuation of the hypothetical situation. The intent of these questions is to elicit the respondent's consumer surplus for the hypothetical situation or change. The questions may be open ended, allowing a respondent to fill in the blank, so to speak, with a dollar figure; they may be closed ended, where the respondent answers yes or no to a minimum or maximum WTP; or they may take the form of a range of WTP amounts, and the respondent chooses the one closest to their own WTP. Finally, there are questions about the respondent's characteristics, such as income, age, sex, education, and other socioeconomic variables.

If the WTP questions are not open ended, the average WTP of the respondents must be derived statistically. This approach relies on an economic model of consumer behavior, which produces a statistical model to be fitted with the data from the CV survey.

CV surveys have become more sophisticated in recent years. One problem in the CV survey literature is the large variation in survey design, payment vehicle, and valuation format, which makes it difficult to compare results across surveys. A recent book on CV surveys, Mitchell and Carson (1989), should help set standards for the various parts of the CV survey instrument.

3.2.3 Hedonic Models

A third method for estimating the damage to natural resources is termed the hedonic method. When a market good has a single price representing many characteristics, it is difficult to discern the value of any of the good's individual attributes. For example, houses are sold for a single price; yet they contain a bundle of many goods, such as bedrooms, bathrooms, square footage, mountain or lake views, and so forth. Because housing prices vary from house to house, however, a statistical analysis of the variation in house prices and the levels of housing characteristics can uncover the "prices" for these individual characteristics.

If a good traded in a market has unpriced environmental characteristics, hedonic analysis can estimate the prices of these characteristics. For example, this method has long been used to examine the effect of air pollution on property values. While strong statistical relations between property values and pollution levels have been uncovered, these relations bear only tenuous connections to individuals' WTP for improved air quality. Moreover, the hedonic method cannot distinguish the different effects of a change in environmental quality. For the air pollution example, the hedonic results do not enable one to discern the individual effects of pollution on health, visibility, property damage, and so forth. For these reasons, hedonic methods are used less often than the preceding two nonmarket methods for estimating natural resource values.

3.2.4 Other Methods

Factor Income—The factor income method focuses on the economic value of a natural resource as a factor in the production of a marketed good. Damage or improvement to the natural resource will then change the productivity and profitability of firms that use the resource. These changes can be isolated by looking at the flow of income, either actual (if the resource is bought and sold) or inferred (if the resource is available outside of a market), to the natural resource. Like the methods that use a market model, the factor income method must be based on a model of both the production process and the output market of the firms using the natural resource.

Expenditures—An apparent way of measuring an individual's WTP for a nonmarket activity is to measure the level of expenditures on market goods associated with the nonmarket activity. Arguably, the WTP for the activity must be at least equal to the cost of engaging in the activity, so that expenditures could be used as a lower bound for WTP.

There are a number of serious problems with this method. It is rarely the case that expenditures are confined to goods used solely for a single activity at a particular resource site. For example, fishing or hiking equipment can be used at various sites. More importantly, if such expenditures are a necessary part of engaging in the activity, they represent a cost, not the value, of participation. Thus, if the price of fishing equipment fell, this method might produce a lower estimate of the value of fishing, whereas in fact, the consumer surplus from fishing has increased.

Gravity Models—The gravity model is borrowed from geographers and is used to explain the allocation of recreation trips from a population area to alternative recreation sites. Its basic structure relates the level of use of a site to two sets of factors: 1) the price of using the site (usually travel cost) and a measure of attractiveness (e.g., site capacity); and 2) a gravity variable that sums all of the site prices and measures of attractiveness. It is this latter variable that incorporates the effects of the prices (and characteristics) of other sites on the use of a particular site.

While this type of model may be useful for predicting the levels of use for alternative sites, it lacks a solid basis in economic theory. As a result, it is inappropriate for use in estimating the value of nonmarket resource values.

Unit Values—The unit-value method assigns a fixed value to a unit of natural resource "consumption" (e.g., a day of fishing or hiking, or an individual bird or animal) and applies that value to any changes in the availability of that resource. This method is easy to apply and parallels the market price method (in theory). Given a measurable change in the quantity of a natural resource, one need only multiply by the corresponding unit value to obtain an estimate of the value of that change.

Unlike the market price method, there is no easily available and reliable source of data from which to develop unit values. This means that unit values must be developed from existing economic studies, few or none of which may be applicable to the particular instance. Thus, in practice the method ignores variation in site-specific value. Moreover, it cannot account for changes in the *quality* of a resource, and it assumes that any environmental change is not large enough to affect the unit value itself by altering the resource's scarcity, which frequently will not be the case. The direction of these potential biases is impossible to predict. For these reasons, the unit value method is rarely used.

3.3 APPLICABILITY, RELIABILITY, DATA REQUIREMENTS, AND COMPUTATIONAL COMPLEXITY OF METHODS

This section considers a range of issues for each of the major methods intended to measure resource values. (Factor income expenditures, gravity models, and unit values are not discussed further.) The applicability of a method refers to the types of values (market, nonmarket use, and non-use) capable of being measured by the method. Reliability refers to the ability of a method, both in theory and in practice, to produce consistent, accurate estimates of resource values.

3.3.1 Applicability

Market-based methods are most easily applied to marketed natural resources, of course. For example, these methods have been used extensively to measure the potential damage to agricultural crops from air pollution. They can also be applied to commercial fisheries or extractable resources such as oil, coal, or marketed water. These methods may not capture the full value of market resources if the resources have nonmarket use or non-use value. They clearly do not apply where there is no market for a resource or a comparable substitute.

The three major nonmarket methods vary in their applicability. The travel cost method is intended to measure the value of an activity (a "visit") associated with a natural resource or site. For this reason, the travel cost method can be applied to a wide range of outdoor activities; applying it to the more general question of a natural resource's overall value is more difficult. Although it could be applied to marketed activities, a better approach would be one of the market-based methods. Because the travel cost method requires some measure of resource use, it cannot measure non-use values, which are independent of use.

The CV survey method can be applied to any resource value problem. As with the travel cost method, however, market methods are preferred in situations where a market exists for the resource. A CV survey is capable of estimating use and non-use values, either together or separately. The survey design, in particular the exact wording of the questions that address resource values, determines what types of values are measured.

The set of possible applications of CV surveys, however, may be larger than the set of appropriate applications. One of the most important limitations of CV surveys is the level of familiarity of the respondents with the situation to be valued. In general, familiarity increases the expected accuracy of the responses to the hypothetical valuation problem. This suggests that the application of this method should be limited. CV surveys have been widely used to examine the value of recreation, visibility, and human health; whether applications outside these areas reduce the chance for meaningful results is the subject of much debate.

The hedonic method has found its most frequent application in measuring the value of nonmarketed characteristics of marketed goods. This leaves the hedonic method in a grey area between market and nonmarket methods. Although it can measure the value of nonmarket resources, there must be *some* market indirectly tied to these resources for the hedonic method to work. Because of this limitation, hedonic studies rarely are capable of capturing the full use value of environmental resources and are incapable of measuring non-use values.

3.3.2 Reliability

The market methods are probably the most reliable, although this advantage is offset by their limited applicability. These methods are well established and relatively free from controversy. Their reliability quickly deteriorates, however, as the resource in question becomes less of a "pure" market good. Reliability will also decrease if the available data support only a simple model of the resource market.

The reliability of the major nonmarket methods has a wide potential range, depending mainly on the availability of data and the features of the study design. The travel cost method is highly reliable in theory, but its reliability can decline if certain key data are lacking. The most important variables are the value of individuals' travel time and the availability of substitutes. Reliability is also affected by the sampling design, statistical modeling, and estimation techniques chosen. Unfortunately, there is no single standard for conducting a travel cost study, even if an ideal data set is available.

The reliability of a CV survey has sometimes been questioned on *a priori* grounds because, in the words of Kenneth Arrow, a Nobel Prize winner in economics, "Verbal answers don't hurt the way cash payments do." Nevertheless, its use has gained acceptance among most natural resource economists. The most important determinant of the reliability of a CV survey is the accuracy of the survey instrument. To draw conclusions concerning the real world from a hypothetical survey, the survey instrument must replicate as much of the real situation as possible. If the description of the situation in the instrument is at odds with the actual situation, the values elicited will not be representative of the actual situation. For this reason, differences in surveys intended to measure the same resource value can easily produce different results, sometimes significantly so. If the same survey is taken over time, however, Reiling et al. (1990) have shown that the results are consistent.

There are a large number of other determinants of the reliability of a CV survey. Mitchell and Carson (1989) provide a detailed consideration of this issue. Recent attempts to assess empirically the reliability of this method include Adamowicz and Graham-Tomasi (1991), Kealy et al. (1990), and Loomis (1990). The overall conclusion of these and other studies is that the CV method has the potential to be quite reliable; however, it is also subject to relatively wide variation in accuracy if great care is not taken in designing the survey.

The hedonic method is capable of producing reliable statistical estimates of the relations between some environmental characteristics and market values. The method's difficulties lie in extracting resource values from these estimates. It is generally conceded that with an extensive data set the hedonic method can produce reliable estimates of the applicable resource values. Even with such a data set, however, the hedonic method requires a relatively large number of working assumptions and statistical restrictions. Inattentiveness to these details will seriously undermine the reliability of the hedonic method.

3.3.3 Data Requirements and Computational Complexity

The data requirements for most of these methods are extensive. Because economic benefits can be quantified only by uncovering human values, a large-scale assessment of resource values must gather a substantial amount of information from the affected human population. In the case of non-use values, even the decision of how to define the affected population is a formidable task because, in theory, a natural resource may generate existence or other non-use values for any individual with knowledge of that resource.

For all of the methods, there is a tradeoff between the extent of data collection and the accuracy of the estimated resource values. Most of the methods need certain minimum types and amounts of data; a more extensive data set allows more complex economic models to be used, usually improving the accuracy of the estimates by a significant amount. Although rough or preliminary estimates can be obtained with the minimum data set, the data needs of these models are open ended.

The simplest market method—market price—requires few data and little computational effort. Its estimates will be highly inaccurate, however, if the method is applied in the wrong situations. The data and computational effort required for the other market methods (except the appraisal method) increase with the sophistication of the underlying economic model of the market.

The major nonmarket methods commonly require original data collection, which can be extensive and very costly. The travel cost method requires data on behavior; resource or site characteristics, both for the resource or site affected and possible substitutes; and the characteristics, especially the value of leisure or travel time, of individuals who have access to the site (including those who do not visit the site). Data may have to be collected from a number of different sources. Depending on the statistical model chosen, the computational effort involved can be significant.

A CV survey has the advantage of collecting data from a single source: the sample of respondents. Because of the potential problems stemming from a poorly designed survey, considerable effort should be devoted to developing and testing the survey instrument. The computational requirements of a CV study are the same or less than those of an advanced travel cost model. A survey with an open-ended valuation format—respondents are simply asked to give a dollar WTP—requires relatively little computational effort. For other types of CV survey, or for a travel-cost study, the potential statistical biases are relatively greater and more numerous, and considerable statistical expertise is needed to avoid or minimize these biases.

The hedonic method requires transaction data (i.e., information on individual sales) on the market good that is tied to the environmental resource of interest, as well as data on the characteristics of the good for each transaction. These requirements are difficult to meet in many cases. The computational complexity of the hedonic method can exceed that of the other two major nonmarket methods. In addition, knowledge of the underlying economic theory is essential to the interpretation of its results.

3.3.4 Summary

The relative applicability, reliability, data requirements, and computational complexity of each of the main methods discussed above are summarized in Table F-3. It should be clear that there is no single method that is preferable to all others. The exception is for the measurement of non-use values: The only method capable of measuring these values is the CV survey method. In all cases, enhanced reliability comes at the expense of greater data collection and computational complexity, which increase the cost of using a method.

TABLE F-3. APPLICABILITY, RELIABILITY, DATA REQUIREMENTS, AND COMPUTATIONAL COMPLEXITY OF MAJOR METHODS

Method	Applicability	Reliability	Data Requirements and Computational Complexity
Market price	Very low	High	Low
Advanced market methods	Low	Medium to high	Medium to high
Travel cost	Medium	Medium	Medium to high
Contingent value survey	High	Medium	High[a]
Hedonic	Low	Low to medium	High

[a] This rating reflects the relatively high amount of effort needed to ensure a valid survey instrument.

4. THE TOTAL VALUE APPROACH TO STANDARD SETTING

The total value approach to standard setting uses the basic economic model of maximizing net benefits. There are two main cases to consider: choosing from a set of discrete, site-specific cleanup standard alternatives; and choosing from a continuum of possible standards. In addition, there are complications that arise when the benefits or costs of setting a standard at one site or site unit are affected by the actions taken at other sites; complications also arise when the benefits and costs of cleanup are distributed over time and must be balanced against the possibility of natural recovery.

The next section lays out the basic model for determining the total value of a site-specific cleanup standard. The environmental benefits and costs of a given standard are compressed into simple functions. Sections 4.2 and 4.3 then consider the selection of an optimal standard, or the standard that maximizes total value. Section 4.4 considers an important complication: the possibility that the environmental benefits or costs at different sites are related. Finally, Section 4.5 considers the consequences of choosing a "nonoptimal" site-specific standard.

4.1 THE TOTAL VALUE OF A SITE-SPECIFIC CLEANUP STANDARD

Consider an action that will increase the sediment quality at a given site. Actions taken today will increase the quality immediately; the passage of time will increase it further until a steady-state quality is attained. For simplicity, assume that all of the cleanup action takes place at time zero.

A simple model captures the total value of the cleanup action. For a specific site, let A represent a possible cleanup action and $C_D(A)$, the direct costs of taking the cleanup action. Given some choice of A, the sediment quality will follow a path over time, reaching the site-specific standard, S, by the specified time of compliance. Following the cleanup action, there is a stream of environmental benefits, $B(t,A)$, and environmental costs, $C_E(t,A)$, which are functions of time and the action chosen. The total value of the cleanup action is expressed in the following equation:

$$TV(A) = \int_{o}^{\infty} [B(t,A) - C_E(t,A)]e^{-rt}\,dt - C_D(A) \qquad 2.1$$

where:

r = the discount rate.

If there is a single action capable of attaining a given standard, S can be expressed as a function of A, or $S = F(A)$. In turn, F(A) can be inverted to express A as a function of S, or $A = F^{-1}(S)$. Substitution of this function into Equation 2.1 gives the following:

$$TV(S) = \int_{o}^{\infty} [B(t,S) - C_E(t,S)]e^{-rt}\,dt - C_D(S)$$

or

$$TV(S) = TB(S) - TC_E(S) - C_D(S) \qquad 2.2$$

where:

TB = total discounted environmental benefits integrated over time

TC_E = total discounted environmental costs integrated over time.

The expression in Equation 2.2 captures the total value of setting the site-specific sediment standard at the level S.

If there is more than one action capable of achieving a given standard, the total value of S is derived in the following way. For a given site, first find the set of actions, {A}, capable of achieving S; compute TV(A) from Equation 2.1 for each A in {A}; and then choose the action, A*, that maximizes TV(A). TV(A*) is then the total value of S.

4.2 OPTIMAL STANDARD SETTING: CONTINUOUS RANGE

The total value approach to standard setting seeks to find the standard that maximizes total value, or the "optimal" standard. This can be done by choosing an optimal standard from a continuous range or from a set of discrete alternatives. This section discusses the first approach; the next section considers the second approach.

Consider the task of choosing the optimal standard from the range [SQS_0, $MCUL_{10}$].[2] The optimal standard, S*, is the solution to the following maximization problem:

$$\underset{S}{\text{Maximize}} \qquad TV(S) = TB(S) - TC_E(S) - C_D(S) \qquad 2.3$$

subject to the constraint $MCUL_{10} \geq S \geq SQS_0$. This solution comes from the first order condition:

$$\frac{\delta TB(S)}{\delta S} - \frac{\delta TC_E(S)}{\delta S} - \frac{\delta C_D(S)}{\delta S} = 0 \qquad 2.4$$

and the satisfaction of the sufficient second-order conditions for a maximum to exist.[3]

Taking the derivative of a total benefit or total cost function produces the marginal benefit or marginal cost function. These functions measure the change in benefits or costs that results if the sediment standard is lowered by a "small" amount. The expression on the left-hand side of Equation 2.4 then has a straightforward economic interpretation: set the site-specific standard at the point where the marginal benefit of a stricter standard (the first term) equals the marginal cost of a stricter standard (the second and third terms). Figure F-4 presents a graphical illustration of the solution to Equations 2.3 and 2.4. At S*, the total value can be measured as the area between the marginal benefit and marginal cost curves.

The constraint on the range of S* (i.e., $MCUL_{10} \geq S^* \geq SQS_0$) means that the optimal standard may be one of the endpoints of this range. Let S^*_U be the optimal standard derived from the maximization problem in Equation 2.3 without the constraint ($MCUL_{10} \geq S \geq SQS_0$); let S^*_C be the constrained optimal standard. If $S^*_U < SQS_0$ or $> MCUL_{10}$, then the S^*_C equals SQS_0 or $MCUL_{10}$, respectively.

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[2]Assume that $MCUL_{10}$ and SQS_0 have been scaled so that $MCUL_{10} > SQS_0$. This means that a standard equal to SQS_0 produces "higher quality" sediment than a standard equal to $MCUL_{10}$. The subsequent analysis describes the total value of attaining different levels of sediment quality.

[3]A standard textbook for maximization problems in economic analysis is E. Silberberg (1990).

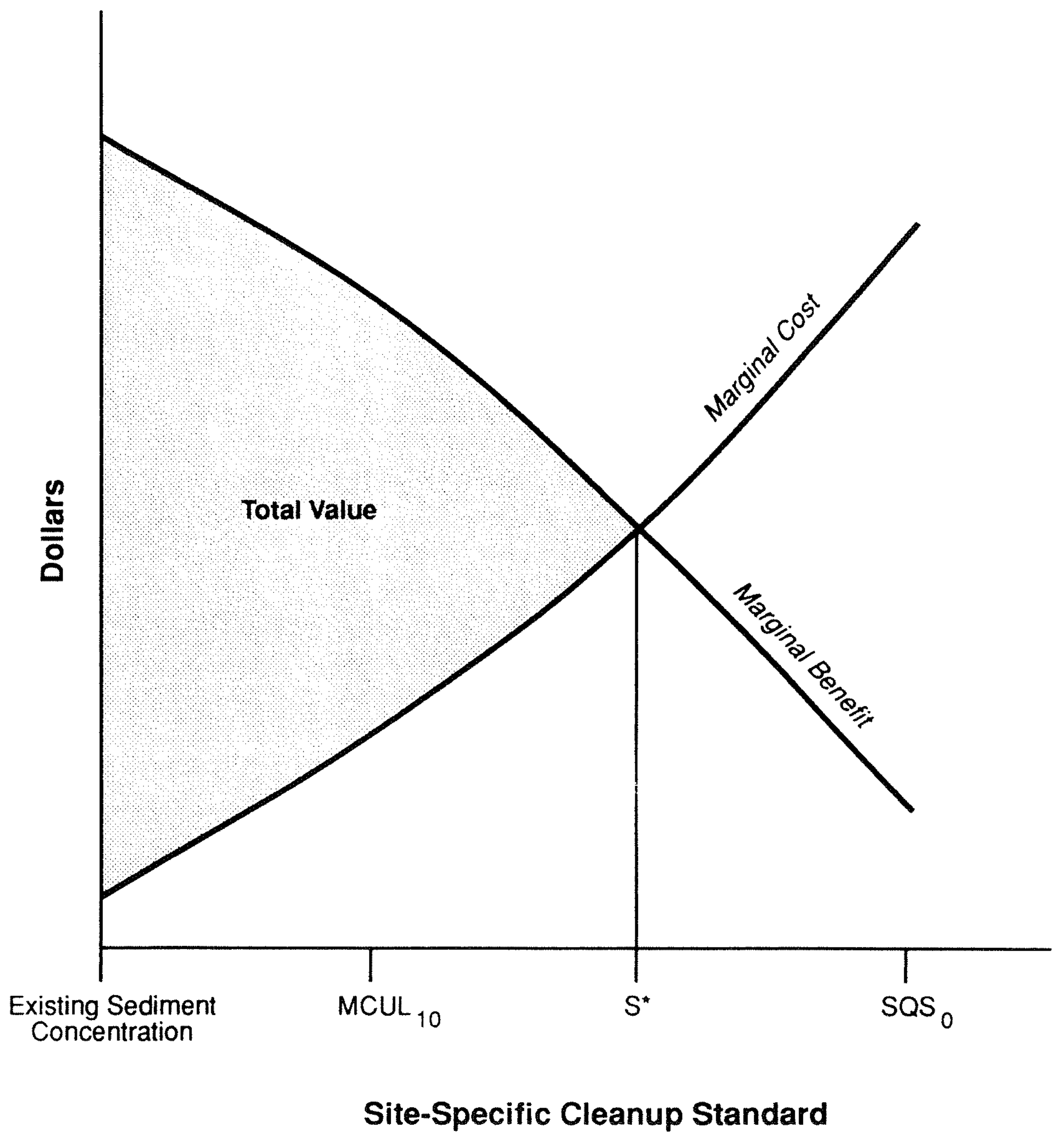

Figure F-4. The choice of an optimal cleanup standard.

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There are good reasons for believing that the first case ($S^*_U < SQS_0$) will rarely arise, however. SQS_0 is defined as "sediments that have no adverse effects on biological resources, and correspond to no significant health risk to humans."[4] Unless such sediments have non-use values, this definition implies that the total benefits of sediment quality reach their maximum at SQS_0. If total benefits increase up to SQS_0 in a "smooth" manner, it must be that the marginal benefit of improved sediment quality—the first term on the left-hand side of Equation 2.4—is zero at SQS_0. In this case, the first-order condition in Equation 2.4 cannot be met at $S \geq SQS_0$ as long as marginal cost—the second and third terms on the left-hand side of Equation 4—is positive. Therefore, it is unlikely that the total value approach will ever justify SQS_0 as the optimal standard without an appeal to significant non-use benefits or zero marginal cost.

4.3 OPTIMAL STANDARD SETTING: DISCRETE ALTERNATIVES

Application of the total value approach to a continuum of standards requires the formulation of explicit, continuous functions to measure costs and benefits. This may be an unrealistic requirement for all but the most important of cleanup actions. A different way of using the total value approach is to consider only a limited number of alternatives.

There is no way of determining the best set of discrete alternatives *a priori*. Because the allowable range of standards contains a numerical minimum (SQS_0) and a numerical maximum ($MCUL_{10}$), these two alternatives must always be included.

Other alternatives could be included based on distinct cleanup possibilities or scales. For simplicity, designate a single other alternative, an intermediate standard, S_{MED}, that lies between SQS_0 and $MCUL_{10}$, and suppose $MCUL_{10} > S_{MED} > SQS_0$.

With discrete alternatives, the total value approach compares the value derived from Equation 2.2 for each alternative standard. The hypothetical set has the associated values listed in Table F-4. The best action is then the one with the highest total value.

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[4]WAC 173-204-300.

TABLE F-4. TOTAL VALUE APPROACH: DISCRETE ALTERNATIVES

Sediment Standard	Costs of Action	Environmental Effects	Total Value
$MCUL_{10}$	$TC_A\ (MCUL_{10})$	$TB(MCUL_{10}) - TC_E(MCUL_{10})$	$TV(MCUL_{10})$
S_{MED}	$TC_A\ (S_{MED})$	$TB(S_{MED}) - TC_E(S_{MED})$	$TV(S_{MED})$
SQS_O	$TC_A\ (SQS_O)$	$TB(SQS_O) - TC_E(SQS_O)$	$TV(SQS_O)$

4.4 MULTIPLE SITES

The discussion of the total value approach in the previous two sections has focused on a standard for a single site. In many cases, the standard will actually be set for a site unit. Where the benefits or costs of developing standards for two or more sites are related, the total value approach suggests that the set of site-specific standards be chosen jointly, rather than independently. The failure to do so will produce an inefficient choice of a site-specific standard in each case, although the direction of bias—too strict or too lenient—cannot be predicted *a priori*.

The problem of multiple sites is illustrated with a simple example. Suppose there are two neighboring sites where the environmental benefits flowing from each site are a function of the sediment quality of each site. An action taken on one site will not affect the cost of a given action on the other site; similarly (for simplicity), the environmental costs of an action on one site are independent of the action taken on the other site. The total value of a site-specific standard for each site is then:

$$TV^1(S_1) = TB^1(S_1,S_2) - TC^1{}_E(S_1) - C^1{}_D(S_1) \qquad 2.6$$

$$TV^2(S_2) = TB^2(S_1,S_2) - TC^2{}_E(S_2) - C^2{}_D(S_2) \qquad 2.7$$

where:

S_1 = site-specific standards for the first site

S_2 = site-specific standards for the second site.

If each site-specific standard is selected separately, the choices made using the total value approach will not be correct.

To illustrate this concept, maximize TV^1 with respect to S_1 to obtain:

$$MB^1(S_1,S_2) - MC^1{}_E(S_1) - MC^1{}_D(S_1) = 0 \qquad 2.8$$

where:

MB = marginal benefit

MC = marginal cost.

If the choice of the standard for the first site is made based on the *current* level of S_2, this choice will not satisfy Equation 2.8 after the level of S_2 is changed through the cleanup of the second site if $\delta MB^1/\delta S_2 \neq 0$.

Figure F-5 illustrates this problem when $\delta MB^1/\delta S_2 < 0$.[5] The initial level of sediment quality at the second site is S_2. Assuming this level will not change, the choice of a site-specific cleanup standard proceeds, resulting in a choice of S_1*. Any cleanup action at the second site, however, will increase S_2 to S_2'. This causes $MB^1(S_2)$ to decrease to $MB^1(S_2')$, resulting in an optimal standard of S_1**. If the change in S_2 and the consequential shift in MB^1 are not taken into account, the choice of S_1* will be incorrect. A similar problem exists, of course, for the choice of S_2*.

If the total value approach uses exact mathematical formulations of benefits and costs, the problem of multiple, related sites is solved by choosing the corresponding site-specific standards through a joint maximization. If the approach is used for a finite number of alternatives (far more likely because of the difficulties in defining the exact mathematical formulations), it is still possible to address this problem. As alternatives are developed for each site, the associated benefits and costs should be estimated for *sets* of alternatives, $\{S_1,S_2,\ldots,S_N\}$. The total value of each set can then be calculated; the one with the greatest total value is the best set of standards.

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[5]This means that an increase in sediment quality at the second site reduces the marginal benefit of increasing the sediment quality at the first site. For example, sediment quality at both sites might affect a crab population. An increase in the sediment quality at either site will increase this population, which increases the value of crabs. If this value, however, increases at a decreasing rate (e.g., total value of crabs = number of crabs), an increase in the sediment quality at one site will decrease the marginal benefit of increasing the sediment quality at the other site.

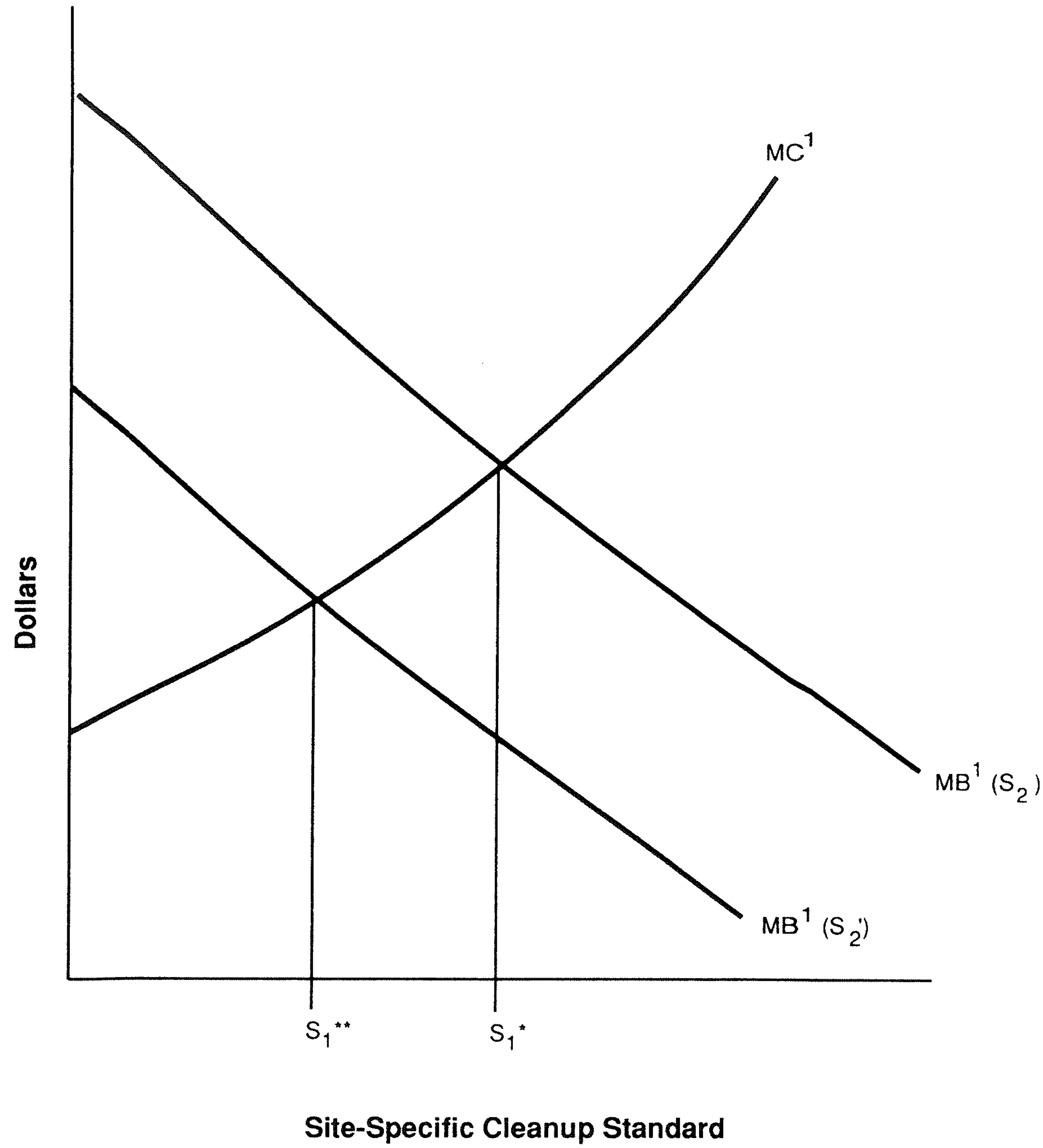

Figure F-5. Site-specific cleanup standards for related sites.

4.5 NONOPTIMAL STANDARDS

The problem of multiple sites brings out another use of the total value approach: analyzing the consequences of choosing an incorrect or "nonoptimal" standard. In general, if a standard, S′, is chosen that is not equal to S*, the optimal standard (chosen by solving the maximization problem in Equation 2.3), there is an economic loss that increases the further S′ is from S*. This applies whether S′ is less than or greater than S*.

Table F-5 contains an example. S* is the optimal standard, and S′ and S" are two alternate choices. If S* is chosen, the total value exceeds the total value of any other standard. The total value of S* therefore represents a benchmark against which other standards should be judged. If S′ is chosen instead of S*, the total value of S′ is positive but there is a loss of $70,000 in comparison to S*; similarly, the choice of S" results in a loss of $30,000. Figure F-6 presents this concept graphically. The area between the marginal benefit and cost curves, up to any standard, measures the total value of that standard. (Where marginal cost exceeds marginal benefit, the area is negative, reducing the total value of standards beyond S*.) For standards below S*, such as S′, there is a loss equal to the shaded triangle, which increases the further the standard is from S*. For standards above S*, the same is true.

TABLE F-5. LOSS FROM CHOOSING A NONOPTIMAL CLEANUP STANDARD

Cleanup Standard	Direct Costs (1)	Environmental Costs (2)	Environmental Benefits (3)	Total Value (3) − (1) − (2)	Loss from Nonoptimal Standard
S′	$100,000	$25,000	$130,000	$ 5,000	$70,000
S*	175,000	50,000	300,000	75,000	--
S"	250,000	80,000	375,000	45,000	30,000

If the exact benefit and cost functions are known, the losses from standards other than S* can be calculated; however, if this is the case, the choice of S* is clearly possible and no loss need be incurred. Even if the exact functions are not known, the total value approach can be used to suggest the potential magnitude of losses from nonoptimal standards. The larger are these potential losses, the greater is the value of accurately determining the optimal standard.

One of the major determinants is the relation between sediment quality and marginal benefits and costs. The steeper either curve rises or falls as sediment quality changes, the greater is the potential loss from a nonoptimal standard a given distance away; flatter curves produce lower potential losses [Figures F-7(a) and (b)]. A second determinant is the range of sediment quality covered between $MCUL_{10}$ and SQS_0. The smaller the effective distance (in terms of changes in

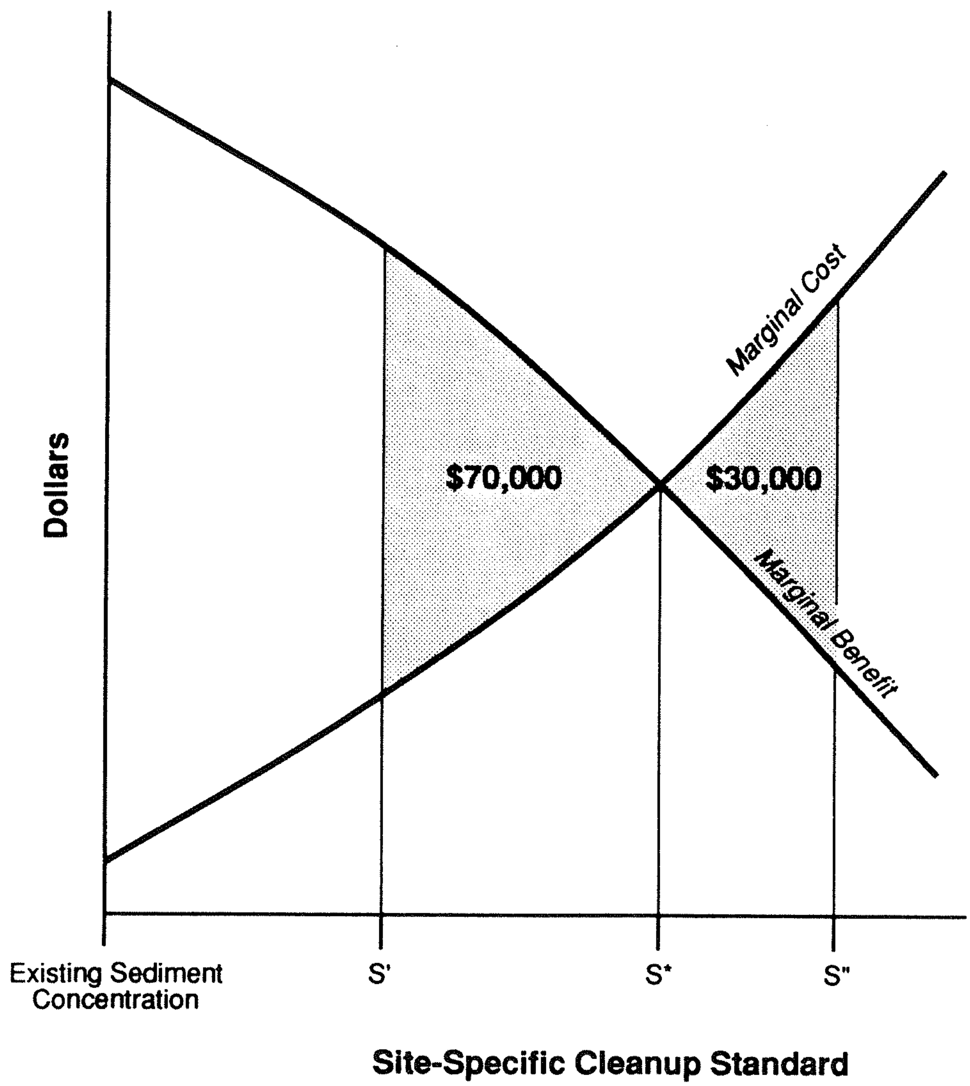

Figure F-6. Losses from a nonoptimal cleanup standard.

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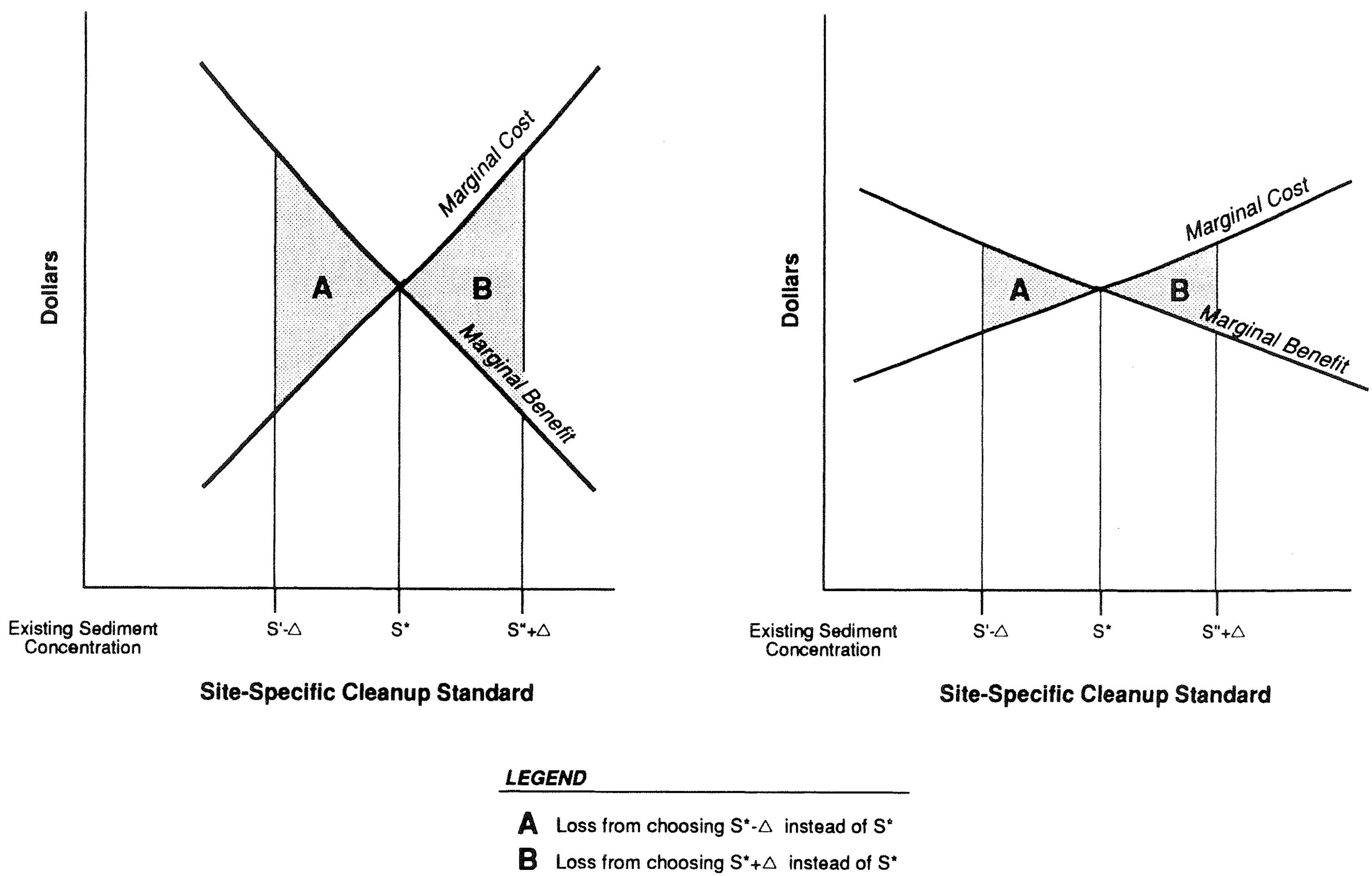

Figure F-7. Magnitude of losses from a nonoptimal cleanup standard.

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environmental effects or cleanup costs) between $MCUL_{10}$ and SQS_0, the lower is the potential loss from a nonoptimal standard.

The use of the total value approach can therefore be evaluated according to this approach's own criterion of economic value. The approach has the advantage of increasing the efficiency of choosing a site-specific standard; it has the disadvantage of being relatively expensive to use. The magnitude of its advantage is lower in certain cases than in others. It may be possible to establish a method for identifying these cases in advance. If this could be done, a decision to use the total value approach could be made based on the expected net benefits of using this method compared to other methods that might be less likely to choose the optimal standard.

5. SUMMARY

The total value approach seeks to find the site-specific cleanup standard that maximizes the net economic benefits of the cleanup action. Because the environmental effects of the action must be translated into economic values, this approach is difficult and expensive to use. Choosing the optimal standard from a continuum of standards requires explicit mathematical models of the relations between sediment quality and environmental effects, and between those effects and economic values; choosing the best standard from a finite number of alternatives is less difficult, particularly for comparing logical alternatives such as $MCUL_{10}$ and SQS_0.

When potential cleanup sites are clustered together or their sediment quality contributes to the common environmental quality, setting site-specific standards independently may result in a biased set of standards. The magnitude of the bias is hard to predict; however, it may be possible to identify certain cases where bias, either from the problem of multiple sites or from the failure to use the total value approach accurately or at all, results in insignificant economic losses.

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APPENDIX G

Organic Carbon Normalization of Sediment Data

TECHNICAL INFORMATION MEMORANDUM

ORGANIC CARBON NORMALIZATION OF SEDIMENT DATA

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CONTENTS

1. INTRODUCTION

All sediment data collected in Washington State are evaluated using the Sediment Management Standards (SMS), Chapter 173-204 WAC. Under the SMS rule, the numerical sediment standards for most organic chemicals are organic carbon normalized. Consequently, all sediment samples that are analyzed for organic chemicals must also be analyzed for organic carbon to facilitate comparisons with the numerical standards.

This technical information memorandum describes why some sediment data are organic carbon normalized, how organic carbon data are collected and analyzed, provides an equation for organic carbon normalizing data, and explains how to evaluate historical data for which organic carbon data are not available. Finally, guidelines are presented for determining when it may not be appropriate to organic carbon normalize data.

For questions on the enclosed information or for further information, please contact the Sediment Management Unit at (SCAN 585)206/459-6824, or contact the NWRO or SWRO Sediment Technical Specialist.

2. WHY SEDIMENT DATA ARE ORGANIC-CARBON NORMALIZED

Concentrations of organic contaminants (particularly nonpolar, nonionizable chemicals) and the toxicity of these contaminants in sediments have been observed to correlate well with the organic carbon content of sediments (DiToro et al., 1991; Lyman, 1982; Roy and Griffin, 1985). Nonpolar contaminants in sediments or water preferentially partition into the organic material in sediments because of the similar chemical nature of the organic material to the nonpolar organic contaminants. Contaminants that form ions, such as acids, bases, phenols, and metals, do not partition as strongly into the organic fraction in sediments.

DiToro et al. (1991) and others have reported that the toxicity of nonionic organic chemicals in sediments appears to be correlated to the concentration of those chemicals in the organic carbon fraction of sediments, but is not well-correlated with the overall (dry weight) concentration of the chemicals in sediments. Therefore, the concentrations of contaminants in the organic fraction of sediments may be more relevant than dry weight concentrations for setting standards that are intended to prevent adverse biological effects.

In addition, because nonpolar organic contaminants are primarily associated with the organic matter in sediments, these contaminants move in the environment along with the organic fraction in sediments and may also move along with suspended organic matter in water. Therefore, gradients of chemical concentration associated with a source may be more easily observed when the data are OC-normalized than when they are presented in dry weight.

The Sediment Management Standards criteria for nonionizable organic chemicals have been set on an OC-normalized basis. Because the bioavailability of acids, bases, other ionizable organic chemicals, and metals are generally not controlled by organic matter in sediments, standards for these contaminants are set on a dry weight basis.

3. COLLECTING AND ANALYZING ORGANIC CARBON DATA

The organic carbon content of sediments is measured and referred to as *total organic carbon* (TOC). TOC refers to the total amount of organic carbon in the sediment, and does not include mineralized carbon present as carbonates or bicarbonates. These inorganic forms of carbon do not substantially affect the partitioning of organic chemicals, and are removed from the sample by the laboratory.

TOC samples may be collected in glass or plastic containers. A minimum sample size of 25 grams (wet weight) is recommended. Because a special bottle is not required, sediments for TOC analysis may be combined with sediments for other analyses that will be performed at the same laboratory. Samples should be stored frozen and can be held for up to six months if frozen.

Detailed methods for analyzing TOC samples may be found in the 18th Edition of *Standard Methods for the Examination of Water and Wastewater* (Franson, 1992). Method 5310B is recommended, slightly modified for sediment samples. A description of the method is attached as an addendum (*Clarification: Recommended Methods for Measuring TOC in Sediments*, K. Bradgon-Cook). The laboratory calculates the amount of carbon that was present in the sample from the amount of CO_2 released during combustion. TOC values are reported as percentage of the dry weight sample.

Nearly any full-service laboratory is equipped to perform this analysis, which costs approximately $60 per sample.

4. ORGANIC CARBON NORMALIZATION OF DRY WEIGHT DATA

As discussed in Section 5, organic carbon (OC) normalization is performed on a sample-by-sample basis, because TOC values vary from station to station. Because some site-specific evaluation is required (see Section 7), OC normalization should be performed by the project manager or consultant who receives data from the laboratory. Laboratories are generally not expected to perform the normalization.

To convert chemical concentration data expressed as mg/kg dry weight to mg/kg OC, divide the dry weight concentration by the percent TOC (expressed as a decimal), as shown in the following equation:

$$\text{mg/kg OC} = \frac{\text{mg/kg dry weight}}{\text{kg TOC/kg dry weight}}$$

where: mg/kg OC = milligrams of the chemical per kilogram of organic carbon

mg/kg dry weight = milligrams of the chemical per kilogram of dry weight sample

kg TOC/kg dry weight = percent total organic carbon in dry weight sample (expressed as a decimal; for example, 1% TOC = 0.01)

Although data are typically reported in mg/kg, data reported in ug/kg, ppb, or ppm can also be used in the above equation. For example:

$$\frac{\text{2 ug phenanthrene/kg dry sediment}}{\text{0.01 kg TOC/kg dry sediment}}$$

= 200 ug phenanthrene/kg TOC
= 200 ppb phenanthrene, OC-normalized.

Because this conversion is tedious to do by hand for large data sets, the data may either be entered into a spreadsheet or database that can be used to perform the conversion. **Contractors providing sediment data for permit applicants, cleanup proponents, or for Ecology should perform the normalization (for nonionic organic chemicals) and report the data for these chemicals both as dry weight and as OC-normalized data.**

5. TYPICAL TOC VALUES FOR SEDIMENTS

TOC values vary widely in the natural environment. A range of 0.5-3 percent is typical for Puget Sound marine sediments, particularly those in the main basin and in the central portions of urban bays. For example, the Puget Sound Ambient Monitoring Program reports a mean TOC value of 1 percent (PSAMP, 1990). TOC values less than 0.5 percent are commonly found in sandy or gravelly areas, erosional areas, or areas with fast-flowing currents (including rivers). In addition, the percent organic carbon in subsurface sediments usually decreases with depth, to as little as 0.01 percent.

Natural TOC values greater than 3 percent are common in nearshore environments. On occasion, natural TOC values of up to 12-15 percent have been observed in Puget Sound and other areas, particularly in depositional and/or quiescent areas where organic matter may collect. Natural TOC values may be much higher in marshy areas or other wetlands environments.

TOC values may also be artificially elevated in sediments that are heavily contaminated with organic substances (sewage, petroleum hydrocarbons, wood chips). Sewage and organic chemicals will typically raise TOC values by at most a few percent; in a majority of the cases, the effect will be negligible. However, organic debris such as wood chips can raise the TOC value by anywhere from several percent to 50 percent or more.

Because TOC values may vary widely within a single site, organic carbon normalization is preformed on a station-by-station basis. **Therefore, each sample that is analyzed for nonionizable organic contaminants must also be analyzed for TOC.**

6. EVALUATION OF HISTORICAL DATA SETS

Collection of TOC data is currently required for all sediment sampling to allow comparison to numerical sediment standards. However, many historical data sets are not OC-normalized and may not contain station-by-station TOC data. If any TOC data are available for the data set, it is recommended that a conservative value be chosen from the data available that represents the lowest percent TOC observed at the site. If different areas of the site appear to have widely varying levels of TOC, a different value may be chosen for each area that represents the lower end of the range of TOC values for that area. The professional judgment of the site/permit manager should be used to select an appropriate value in each case.

If TOC data were not included in the data set, data may be available from other studies in the same area. The SEDQUAL database may be consulted to determine whether TOC values are available for the area of interest. Again, a value should be chosen that represents the lower end of TOC values for the area, to insure that the OC-normalized concentrations calculated using the general TOC value are protective. If no TOC data are available for the area of interest, the Sediment Management Unit or a regional sediment technical specialist should be consulted to determine an appropriate TOC value to use for the comparison.

7. WHEN ORGANIC-CARBON NORMALIZATION MAY NOT BE APPROPRIATE

There are several situations, including those described below, in which it may not be appropriate to OC normalize sediment data. For additional information or guidance on data evaluation and presentation for these situations, contact the Sediment Management Unit or a regional technical specialist. **Because of the variety of uses to which sediment data are put, sediment data for nonionic organic chemicals should be reported both as dry weight and as OC-normalized data.**

In areas where the TOC is very low or very high, biological testing or use of dry weight concentrations should be considered along with OC-normalized concentrations in evaluating the extent of contamination and potential biological effects.

For example, if TOC values are very low (e.g., 0.1-0.2), it is even possible for background concentrations of organic chemicals to exceed the Sediment Quality Standards when OC-normalized. In this situation, it may be appropriate, on a site-specific basis, to use Apparent Effects Thresholds (AETs) expressed as dry weight (see PSEP, 1988) to evaluate sediment toxicity. Please contact the Sediment Management Unit for assistance in evaluating such data.

Conversely, if TOC concentrations in sediments have been increased above normal concentrations by organic contamination (such as wood chips, sewage, or petroleum), the OC-normalized values may be inappropriately low. In these cases, although the OC-normalized chemical criteria would not be exceeded, the sediments may still cause adverse biological effects and may therefore exceed the narrative standards or biological criteria. To address this concern, if the organic chemicals or substances that are the primary contributors to the elevated TOC levels are known, the contribution of the organic contaminants to the percent TOC may be determined through analytical methods and subtracted from the TOC value before OC normalizing. Alternatively, as described above, biological testing or dry weight AETs may be used to evaluate sediment toxicity.

Bulk sediment concentrations expressed as dry weight are used to make decisions regarding treatment and disposal of sediments. Currently, the Puget Sound

Dredged Disposal Analysis (PSDDA) program uses dry weight data to determine whether sediments can be disposed of in open-water disposal areas. In addition, upland disposal options require evaluation of whether the sediment exceeds land disposal restrictions and dangerous/hazardous waste thresholds, based on dry weight concentrations. For treatment alternatives, the average dry weight concentrations of chemicals in sediment may be used to predict the effectiveness of processes such as bioremediation or chemical stabilization/solidification.

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CLARIFICATION

RECOMMENDED METHODS FOR MEASURING TOC IN SEDIMENTS

Prepared by Kathryn Bragdon-Cook (Ecology, (206) 493-2931)

INTRODUCTION

Current PSEP protocols for measuring total organic carbon (TOC) in sediment call for drying a sediment sample at 70 degrees C in order to minimize the loss of volatile organic compounds. HCl is then added to the dried sample to remove inorganic carbon and dried again at 70 degrees C. The sample is then combusted using cupric oxide fines as a catalyst at 950 degrees C. A preweighed, ascarite-filled tube is used to capture the resulting CO_2 upon combustion. The tube is then weighed once more to determine the concentration of CO_2 which is used to calculate the TOC in percent dry weight based on total solids in the sample.

Ecology's Technical Information Memorandum, "Organic Carbon Normalization of Sediment Data", recommends Methods 5310A-D, slightly modified, from the 18th Edition of Standard Methods for the Examination of Water and Wastewater (Franson, 1992). These include a wet chemical oxidation method (5310D) and a combustion method (5310B), both using infrared detection (IR). The Department of Ecology Manchester Environmental Laboratory recommends Method 5310B for measuring TOC in wastewater or, with some modification, in sediments. Test Methods for Evaluating Solid Waste (EPA 1986), SW-846 Method 9060 also references Standard Methods for the Examination of Water and Wastewater for measuring TOC levels of solid and hazardous waste.

These methods require some modification for measuring TOC in sediment. Standard Method 5310B calls for the sample to be treated with HCl to convert inorganic carbon to CO_2 which is then purged using purified gas. The sample is homogenized and diluted as necessary. A portion is injected with a blunt-tipped syringe into a heated reaction chamber (packed with a catalyst) of a carbon analyzer using infrared detection. Needle size is selected to be consistent with particle size. Some accredited laboratories have adapted this technique to sediment by drying the sample at 70 degrees C and using an instrument attachment to the carbon analyzer designed specifically for sediment samples (Dohrman sludge/sediment boat sampler attachment, Model 183, for use with the Dohrman DC-80 TOC analyzer). The sample is then combusted and organic carbon in the sediment converted to CO_2 and transported in carrier gas streams to be measured by an infrared detector.

Method 5310 D describes the wet-oxidation method where the sample is acidified and purged as above and oxidized with persulfate in an autoclave from 116 to 130 degrees C. Again, the resultant CO_2 is measured by infrared spectrometry. Adaptation of this method to sediments may be problematic. Reagents and analytical techniques may be adjusted by the laboratory, however, to increase oxidation of organic carbon in sediments.

The carbon analyzer/infrared detection used in these methods identifies characteristic spectral fingerprints as light in the infrared spectrum passes through various molecules. This instrument offers greater sensitivity than the ascarite-filled tube collector for measuring low levels of CO_2.

PROBLEM IDENTIFICATION

The combustion method dries the sediment sample at 70 degrees C to minimize the loss of organic compounds, but 70 degrees C is not enough to drive off all of the moisture in the sample. A minimum temperature of 104 degrees C is needed to ensure a truly dry sample for total solids calculations. At 104 degrees C, however, a significant loss of volatile organics occurs.

In addition, the ascarite-filled tube used to detect CO_2 in the PSEP method is less sensitive than the infrared detector of the wet oxidation method, limiting accurate detection of low TOC concentrations. Comparative data between the two methods are not yet available.

PSDDA Reports, Development of Sediment Quality Values for Puget Sound, lists the 50%, 75%, and 90% TOC percentile concentrations for Puget Sound at 1.31%, 2.30%, and 4.50% respectively. TOC levels for individual test sites, however, vary greatly with some concentrations well below these averages. Low level detection of TOC in these areas is less accurate using the PSEP method.

Because the Ecology sediment clean up program and PSDDA program may overlap on projects, the need exists for consistency in the method used to measure TOC in sediments.

PROPOSED ACTION/MODIFICATION

Standard Method 5310B and SW-846 Method 9060 provide for more sensitive measurement of TOC concentrations in sediment. SW-846 Method 9060 (as modified by Laucks Laboratories for example) can detect TOC in sediments below 0.1%. Analytical precision for the PSEP method is not given in the protocols. For these reasons, utilization of Method 5310B or SW-846 Method 9060 using infrared detection is strongly recommended. Under conditions described below the PSEP method is acceptable.

Based on the lack of analytical error data for the PSEP method and greater instrument sensitivity of the combustion/IR method, the following guideline is given.

Prior to method selection, consideration should be given to the condition of the test site regarding probable TOC levels. When possible, historical data of particular sites should be reviewed to identify probable TOC concentration ranges.

When TOC concentrations are above 2% either method described could be used. Standard Method 5310B or SW-846 Method 9060 should be used for areas where TOC levels below 2% are likely. PSDDA applicants should state in their sampling and analysis plan which method for measuring TOC in sediment is proposed and provide detailed justification.

To correct for true dry weight, with either method, the corresponding total solids analysis should be run twice, once at 70 degrees C and once at 104 degrees C, and the TOC calculation based on dry weight at 104 degrees C.

This document serves as an addendum to Ecology's Technical Information Memorandum noted above. An errata sheet to replace page 3 is included.

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APPENDIX H

Sediment Sampling and Analysis Plan Appendix

The current version and updates are now available on the WA Department of Ecology internet homepage at http://www.ecy.wa.gov/biblio/0309043.html